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CONTENTS

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CORRECTIONS

Volume 59, January, 1931, page 31: Second column, twenty-fourth line from top, change "a" thousand feet to "two or three" thousand feet.

MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY

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NOTES ON LAKE LEVELS

By JESSE W. SHUMAN, C. E.

[Minneapolis, Minn., January 29, 1930]

In Chapter III of his book, Brückner (1) investigates the secular oscillations of lakes without outlets. He studied the Caspian Sea, Great Salt Lake, Lake George, and numerous others in various parts of the world. He sets up five general theses—

(1) Oscillations of lakes with complete outflow are small and follow without much lag, the oscillations of the various water supplies (inflows, springs, etc.)

(2) Oscillations of lakes without outlets are great, and show a very considerable lag in fluctuations, in comparison with the oscillations of their water supply. This lag may be so great that the maximum of the mean water level may not occur until the water supply has passed its peak and receded to its mean value.

(3) Lakes without outlets, whose inflowing rivers or water supplies have pronounced oscillations, show but little lag, and their oscillations are only a small per cent of those of the water supply. The same holds for lakes with level flat shores, in contrast with those having steep shores.

(4) Secondary oscillations of the water supplies, for a no-outlet lake, have no effect upon the latter as long as these oscillations are of small intensity and interfere in their flow with one another. The storage curve of the levels behaves similarily—the rise and fall is either accelerated or delayed.

(5) Lakes with partial, incomplete outlets stand in their behavior between complete outflow and no-outflow lakes.

Brückner now discusses the behavior of the various lakes, fortified with all the available data he could accumulate, both from recorded observations and indirectly obtained, and tabulates the results. Table 1, is a greatly abbreviated presentation of these results, and is given for the purposes of record. These data were assembled over 40 years ago, and with the accumulated observations since that time, should be of unique interest and assistance to a present-day investigator.

It will be noted that Brückner gives data on 7 lakes from 1600 to 1800 A. D. Their rise and fall being also compared to the advance and retreat of the Alpine glaciers. The rhymic swings seem to be well in step with one another. From 1800, the table gives data on 10 lakes in Europe, 11 in Asia, 2 in South America, 4 in North America, 6 in Africa, and 3 in Australia. All of these lakes are without outlets, the better known being: Caspian Sea; Lake George in Australia; Valencia in South America; Honey, Pyramid, and Great Salt Lake in North America.

At the end of Chapter III, Brückner closes with the following: "As the oscillations of the lake levels are of the same nature and occur at the same time, so must also the climatic changes for the countries of the world be similar and occur at the same time. This must be so. Is it possible that climatic oscillations can exist alone (with no effect upon anything else)? Which are the meteorological elements whose changes cause the variations in the lake levels? So far, we are completely in the dark, as the plotting of the meteorological observations alone will not determine it. At any events, it can only be the temperature that is active, which regulates the evaporation, or the rainfall, upon which the supply to the lake depends—perhaps it may be both at the same time. The influence of one oscillation in temperature is not to be underestimated; as first of all, it effects the evaporation from the surface of the lake, hence the level; then also the evaporation of the rain falling on the land, which influences the water supply. Also the effect of an oscillation in rainfall must be twofold—one direct in so far as the abundance of water is determined, which governs the inflow, and one indirect, inasmuch as hand to hand with the rainfall changes, the ratio of clouds vary, which in turn effects the evaporation. We do not know which alone of these factors to ascribe the principal work. We can only say the maximum of the lake levels seems to occur during a cool or wet to cool and wet, and the minimum of the levels to occur during a dry or warm to dry and warm, periods of weather. Quite definite is the conclusion that we can draw from the variation of the lake levels, relative to the position of the peak of the climatic oscillations. The former must not lag inconsiderably behind the latter. The peak of the latter must occur before the peak of the lake level oscillations. How great this lag of the lake is, we have not yet determined—and it must vary from lake to lake. Herein we have, perhaps, an explanation of the different behavior of the individual lakes from their neighbors. At any event, however, the periods of the lake level oscillations happen to occur, with respect to analogous portions of the curve of climatic oscillations, either at periods of maximum to (cold or wet) to (cold and wet), or at periods of minimum to (warm or dry), to (warm and dry)—certainly the same relationship continues to the end of the record. A general idea of lake-level oscillation is given in the following:

Dry or warm to dry and warm	Wet or cold to wet and cold
1720	1740
1760	1780
1800	1820
1835	1850
1865	1880

We know enough from what we have given above about the Caspian Sea, as well as for various lakes, whose meteorological data we have assembled and discussed (Table 1) in detail, to point out the reason for these

oscillations. We will reserve this for later consideration. Sufficient here to say that all over the world, whereever there are lakes without outlets synchronous oscillation exists.

TABLE 1.—*Lakes without outlets up to 1800 A. D.*

[Condensed from the original]

	Alpine glaciers	Caspian Sea
Maximum about 1600	Increase 1595 to 1610	High 1838.
	Increase 1677 to 1681	
	Increase 1710 to 1716	
Minimum about 1720		Low 1715 to 1720.
Rising		Rising.
Maximum about 1740		Maximum 1742 to 1743.
Falling	Decrease 1750 to 1767	Falling.
Minimum about 1760		Minimum 1765 to 1766.
Rising	Increase 1760 to 1786	Rising.
Maximum about 1780		From 1780 (?) higher levels to 1809–1814.
Falling	Slight falling	

Lakes without outlets since 1800 A. D.

	North America			South America—Lake of Valencia	Australia—Lake George
	Honey Lake	Pyramid-Winnemucca	Great Salt Lake		
Minimum about 1800.				Low, 1800	Dry, about 1800.
Rising				Rising	Rising.
Maximum about 1820.				May, 1822, or a little later.	Maximum, 1822 or 1823.
Falling				Falling	Falling.
Minimum about 1835.				Minimum, 1835 (?)–1841.	Dry, 1838–1850.
Rising					Rising.
Maximum about 1850.			Moderate maximum, 1856.		Moderate maximum, 1852.
Falling			Falling		Falling.
Minimum about 1865.	Dry, 1859–1863.	Low, 1862	Minimum, 1861.		Dry, 1859.
Rising	Rising so that high in 1867.	Rising from 1867 on.	Rise before 1867.		Rising.
Maximum about 1880.		High in the 70's.	High in the 70's.	Maximum, 1873–1874; high until 1877.	Maximum, 1894.
Falling		Beginning in the 80's still higher than in 1862.	Falling until 1889.		Falling.

After discussing secular variation of rivers and lakes with outlets, rainfall, and barometric pressure Brückner deals, in Chapter VII, with secular variation in temperature, and certain relationships are disclosed in the following:

TABLE 2.—*Secular variation*

Lakes	Rainfall	Temperature
Minimum, 1720	Dry, 1716/25	
Maximum, 1740	Wet, 1736/55	Cold, 1731/45.
Minimum, 1760	Dry, 1756/70	Warm, 1746/55.
Maximum, 1780	Wet, 1771/80	Cold, 1756/90.
Minimum, 1800	Dry, 1781/05	Warm, 1791/05.
Maximum, 1820	Wet, 1806/25	Cold, 1806/20.
Minimum, 1835	Dry, 1826/40	Warm, 1821/35.
Maximum, 1850	Wet, 1841/55	Cold, 1836/50.
Minimum, 1865	Dry, 1856/70	Warm, 1851/70.
Maximum, 1880	Wet, 1871/85	Cold, 1871/85.

As is well known, Brückner determined from his studies that the length of the period of oscillation in our weather elements was about 36 years, and he points to the above table as indicating this in all three columns. He calls attention to the lag of rainfall behind temperature changes; also in further discussing temperature changes he makes the statement: "There is no doubt but that temperature oscillations are primary, and those of barometric pressure and rainfall are secondary."

Despite Brückner's classical and published studies regarding lakes, but little attention, if any, has been given them by American investigators. The rise and fall of the Great Lakes and Great Salt Lake, have received current newspaper comment from time to time, the oscillations of the former giving rise to some very expensive lawsuits; and while eminent engineers have dealt in their reports regarding the levels of the Great Lakes, and have ascribed climatic changes as the cause, it has been only in a decidedly vague manner.

Streiff (2) first pointed out that the Great Lakes and Great Salt Lake were oscillating in accordance with the cycle discovered by Brückner, and later (4) again referred to these lakes as well as Lake George in Australia. Inasmuch as public interests are much concerned with lake levels, and as so many of our smaller lakes are at extremely low levels, it is thought that these notes might throw additional light on the subject of their oscillations.

The various cycles referred to in these notes, have the following significance:

Secular cycle: The dictionary defines the word "secular," as brought about in the course of ages; occurring or observed once in an age or century. Brückner constantly refers to the secular variation in rainfall, temperature, lake levels, etc., and evidently means thereby the long swing in the climatic elements. Streiff (4) refers to secular cycle as being of variable periodicity, the last three periods being estimated at 70, 60, and 90 years in length, giving an average of about 73 years—the first period being estimated from Douglass's sequoia curve (1911, 11 trees). We adopt Streiff's nomenclature for the meaning of the secular cycle.

Wolf numbers or sunspot secular cycle: This is the long swing in the Wolf numbers; this cycle being low at 1816, high about 1856 and low again about 1906. From 1816 to 1906 is 90 years. This is the same cycle, evidently, as found in tree-ring growth.

Double secular cycle: It is shown in these notes that the secular variation of rainfall, temperature and lake levels appears to be such that there are two HIGHS for ONE of the Wolf numbers secular HIGH—giving rise to what is here called a double secular cycle (double the number of peaks, as in the Wolf numbers secular).

Wolf, solar cycle: By this is meant the cycle of approximately 11 years, the period from sun spot maximum to maximum. This is variable, also.

Double Wolf cycle: This is a cycle of half the solar or Wolf period; it has double the number of peaks as the Wolf. Again, this is Streiff's nomenclature.

Brückner cycle: This cycle is described by Streiff (4) as having twice the solar cycle period, or approximately 22.6 years. It is a variable, depending upon the actual length of two solar cycles. In his book, Brückner shows his cycle as having a variable periodicity, with an average of plus or minus 35 years. But as pointed out by Streiff (4), Brückner did not separate his cycle from what we now call the secular cycle.

HIGH, LOW: These terms in reference to cycles, herein, designate the periods of maximum and minimum values of the ordinates of the cycles.

Figure 3 shows the data on secular variation of rainfall, lake levels, and temperature, as found by Brückner, Table 2, plotted only to show the peaks and troughs at various times, without regard to vertical scale. We note the 30 to 45 year periods that are present in all three graphs. The lag of the lake levels behind the rainfall, and of the rainfall behind the temperature (wet after cold

and dry after warm) is clearly indicated. Brückner's cycle, to him, consisted of twice the solar (4) cycle superimposed upon the Wolf numbers secular cycle, and this latter cycle has been traced in on one of the graphs of Figure 3. It will be noted that there are two HIGHS and two LOWS of the lake levels, for one of the Wolf numbers, secular cycle. Curves are also submitted, accompanying these notes, covering:

Figure 1, Rainfall at Padua, Italy.
Figure 2, Wolf numbers, mean annual smoothed.
Figure 4, Lake Ontario mean annual levels.

weather. These wet periods are reflected in lake levels, as will be shown later. This Padua rainfall record is one of the longest available, and is given here to show that while the Wolf numbers, secular cycle, affects the general swing up and down, the Brückner cycle also operates, and produces more HIGHS and LOWS than the former cycle. It seems probable that the same type of behavior may be expected all over the world, as in every record of rainfall examined by the writer, the Brückner and secular cycles are present. Sometimes they are very faint, but nevertheless present. Also because of the fact that lakes

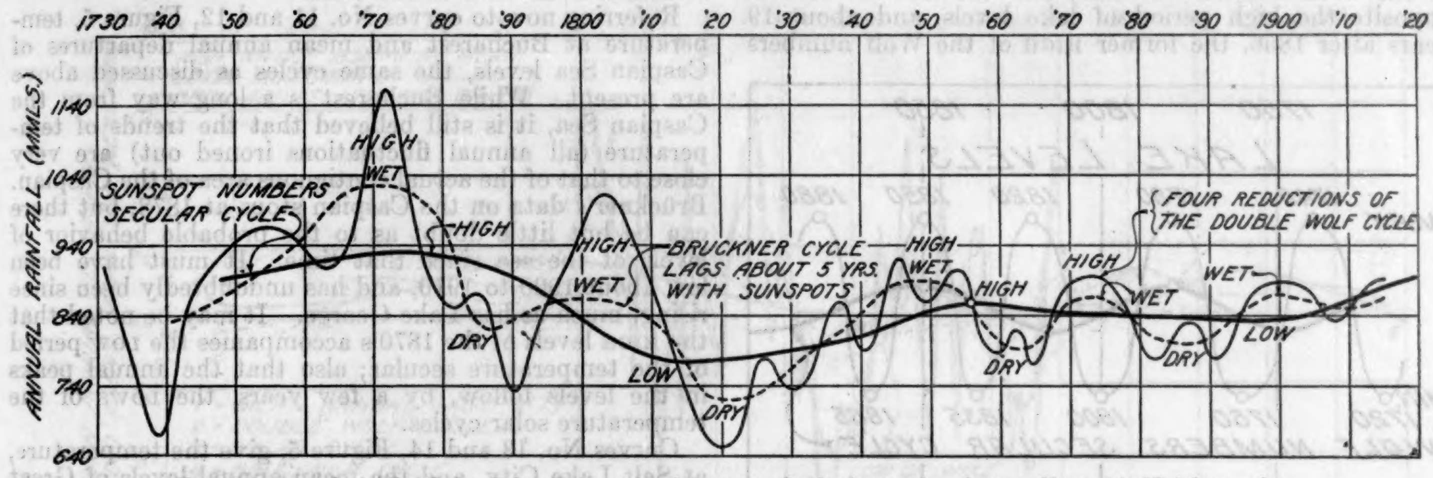

FIGURE 1.—Annual rainfall at Padua, Italy. Note a wet period occurs each side of sun-spot secular HIGH (the crests) of Brückner cycle

Figure 4, Mean annual temperature at Toronto, Canada.
Figure 4, Mean annual temperature at Detroit, Mich.
Figure 5, Mean annual temperature at Sidney, Australia.
Figure 5, Mean annual levels of Lake George, Australia.
Figure 5, Mean annual temperature at Bucharest, Rumania.
Figure 5, Mean annual departure of Caspian Sea levels.
Figure 5, Mean annual temperature at Salt Lake City.
Figure 5, Mean annual levels of Great Salt Lake.

all over the world show certain synchronous swings, as found by Brückner, we may accept this as a fact, until it is disproved by bringing forward a series of raw data, which will fail to yield these cycles.

The curve of smoothed Wolf numbers, Figure 2, is submitted for comparison purposes, showing the Brückner cycle, superimposed on the secular cycle.

Taking up the lake levels, we refer first to curve No. 10, Figure 5, Lake George. Streiff's data (4) for this lake from 1852 to 1905 has been pieced out by data taken from Brückner's book, and the resulting graph gives a

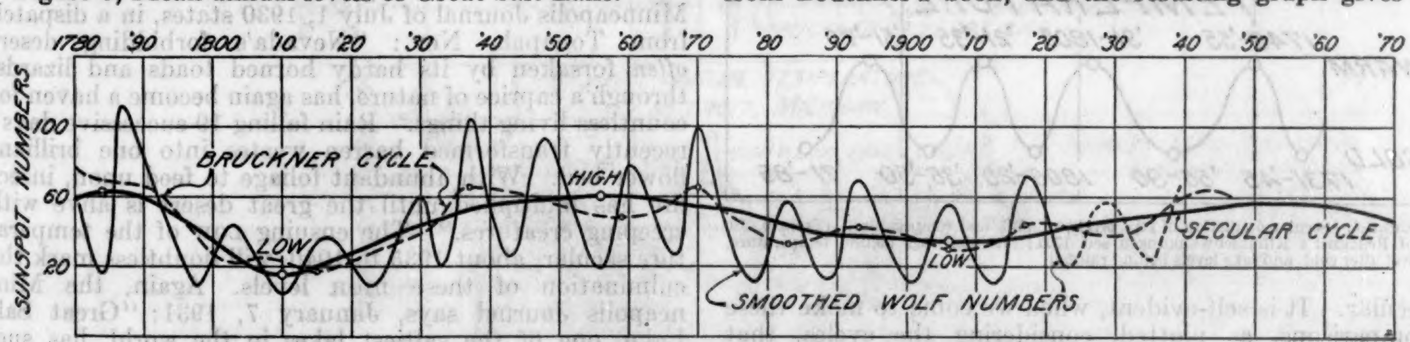

FIGURE 2.—Smoothed Wolf numbers

Figure 6, Lake Ontario cycle analysis.

Considering the Padua rainfall, this is a graph of the annual values greatly reduced, or smoothed. Four reductions were first used to secure the double Wolf cycle, and the latter values were again reduced four times, giving the curve as plotted. The median line drawn through the loops of this curve, gives us the Brückner cycle, and a median line through the latter gives us the Wolf numbers, secular cycle, which was HIGH about 1780 and 1856, and LOW about 1815 and 1900. It will be noted that there is a *crest* of the Brückner cycle on *each* side of (before and after) the HIGH of the secular cycle, which gives rise to two periods of wetter than normal

very good picture of how no-outlet lakes behave in the extreme. The sun-spot secular is shown in heavy smooth line, and the lake-level secular in dotted line. The Brückner cycle oscillates about the double or lake-levels secular, and the latter about the sun-spot numbers secular cycle. In October, 1929, Streiff (4) writes that this lake is already half full again. The curves indicate that a period of high levels is impending. A local Minneapolis newspaper, February 21, 1928, says, in a dispatch from Melbourne, Australia: "Fourteen persons are dead to-day and many are missing in what is believed to be the worst floods in the history of Australia—landslides were occurring at many points—damage to the town of

Grafton alone estimated at $3,750,000—water was 20 feet deep in some streets of Murwillumbah—the Brisbane River in Queensland district already is 26 feet above normal and is rising at the rate of 6 inches an hour." From the foregoing it is quite probable that Lake George will again attain the levels obtaining in the seventies to eighties.

Curve No. 9, Figure 5, is a graph of the mean annual temperature at Sidney, Australia. The solar, Brückner, and secular cycles have been traced in. Note the HIGH of the secular is about 1906, just opposite the LOW period of the Wolf numbers secular; and the LOW at 1875 is opposite the high period of lake levels, and about 19 years after 1856, the former HIGH of the Wolf numbers

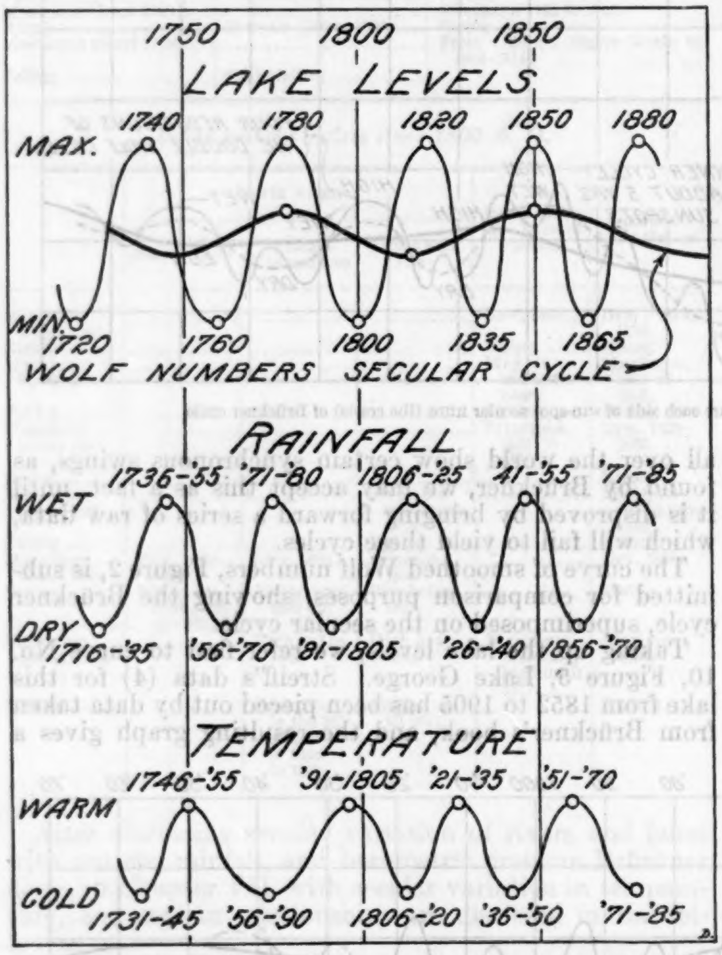

FIGURE 3.—Secular oscillation of lake levels, rainfall, and temperature. (From p. 236 of Brückner's Klimaschwankungen seit 1700.) Rainfall lags behind temperature, wet after cold, and lake levels behind rainfall

secular. It is self-evident, when we come to make these comparisons, as plotted, considering the cycles, that temperature alone must greatly affect lake levels, as at higher temperatures the evaporation must be greater, and vice versa. Thus, HIGH of the temperature secular is synchronous with low lake levels, and LOW of temperature secular with high lake levels.

Attention is directed to the HIGH of the temperature secular at about 1850 (see temperature curve No. 8, fig. 4, for Detroit, going back to 1940), close to Wolf numbers secular HIGH, as well as a HIGH about 1905, the LOW point of the Wolf numbers secular. It is known that the sun's heat output is slightly greater at sun-spot maxima, also this applies to high region of the sun-spot secular. Apparently also the mean temperature on the earth is higher at the LOW period of sun-spot numbers, i. e., 1905, as shown in all temperature graphs. Perhaps there is a decrease in the sun's heat output during sun-spot minima (and at LOW of its secular), but in any event there must be fewer clouds, with a net result of higher than normal temperature. This must be a fact, as examination of rainfall graphs everywhere indicate much less rain at the LOW periods of the Wolf numbers secular cycle. Thus the combined effect of rainfall and temperature on lake levels is to give a secular periodicity to the latter of approximately one-half of the period of the Wolf numbers secular, all as originally shown in Brückner's discussions and data.

Referring now to curves No. 11 and 12, Figure 5, temperature at Bucharest and mean annual departures of Caspian Sea levels, the same cycles as discussed above are present. While Bucharest is a long way from the Caspian Sea, it is still believed that the trends of temperature (all annual fluctuations ironed out) are very close to that of the actual contiguous area of the Caspian. Brückner's data on the Caspian stops at 1878, but there can be but little doubt as to the probable behavior of levels of the sea since that time. It must have been low about 1900 to 1910, and has undoubtedly been since rising, much as has Lake George. It may be noted that the HIGH levels of the 1870's accompanies the LOW period of the temperature secular; also that the annual peaks in the levels follow, by a few years, the LOWS of the temperature solar cycles.

Curves No. 13 and 14, Figure 5, give the temperature, at Salt Lake City, and the mean annual levels of Great Salt Lake (5). This lake has behaved identically with Lake George and the Caspian Sea. It has oscillated over 14 feet between 1873 and 1905. Note that the annual HIGH levels occur about the same time as the crests of the solar temperature cycles, and that these HIGH levels are really lagging behind the former LOWS of the temperature solar cycles. Streiff (4) has already pointed out the impending higher levels of this lake. The last LOW of the temperature solar cycle (curve No. 13) was about 1927–28; and judging from former behavior, the levels are about due to begin their rise (i. e., increased rainfall for the ensuing period is indicated). The Minneapolis Journal of July 1, 1930 states, in a dispatch from Tonapah, Nev.: "Nevada's forbidding desert *often* forsaken by its hardy horned toads and lizards, through a caprice of nature, has again become a haven for countless living things. Rain falling 19 successive days [1] recently transformed barren wastes into one brilliant flower bed. With abundant foliage to feed upon, insect life has multiplied until the great desert is alive with creeping creatures." The ensuing LOW of the temperature secular, about 1935 to 1940, will doubtless mark the culmination of these HIGH levels. Again, the Minneapolis Journal says, January 7, 1931: "Great Salt Lake, one of the saltiest lakes in the world, has succumbed to the cold. Ice was found on the lake yesterday for the first time in the history of the Weather Bureau."

The 19 days of successive rainfall and the formation of ice are simply climatic witnesses, in this region, to what is to follow. The word "often" italicized above by the writer, is significant in that it indicates in a general newspaper dispatch the fact that similar phenomena have occurred before. It is also interesting to note that this wet period at Tonapah came about at the same time as portions of the United States in the East were suffering from one of their worst droughts. This is

[1] This is not strictly accurate; the longest period of days with measurable rain in Nevada for May, 1930, was 11 and the total catch for the 11 days was 1.61 inches. The rainfall average for the State was 2.20 inches or 204 per cent of the May average.—*Editor.*

simply a concrete demonstration of the variation in phase of the Brückner cycles in weather elements in different parts of the country.

Inasmuch as Brückner, by his method of reduction of the raw or observational data did not separate the Brückner from the secular cycle, as we now understand the Brückner cycle (twice the solar cycle period), it appeared to him, just as shown in the examples above that the phase of this cycle plus or minus 35 years, was the same all over the world. If we separate the two, in meteorological data, we will find the phase of the secular cycle to be the same all over the world, and that of the Brückner cycle to vary, either leading, in phase with, or lagging behind the Brückner cycle in Wolf numbers. For the various lakes without outlet, here shown, the phase of the Brückner cycle is about the same, although this is not conclusive that it would be so for every no-outlet lake. For lakes with outflows, the phase of the Brückner cycle varies with the geographic location; viz, for Lake Ontario, the Brückner cycle seems to lead sun spots about 8 years. However, it is fairly easy to detect the Brückner cycle in any lake-level series, having a continuous fairly reliable record, and after levels data have been accumulated covering two complete Wolf numbers secular cycle swings, the behavior of lake levels will be more thoroughly understood.

Temperature oscillations do have a great effect upon the levels as shown by the examples given, and rainfall has not been considered here, because this element has generally been used as the basic active agent in affecting lake levels. More intimate knowledge, of course, can be gained regarding a lake's behavior in levels, by investigating rainfall and temperature together at the same time as levels. The purpose of these notes, however, is to show the reason for the double secular cycle, apparent in lake levels, and the effect of temperature. Securing the average rainfall and temperature (from all stations) surrounding a lake region will give slightly different results, in annual values, but the trends, cycles derived therefrom will not greatly differ from those of a single station in the vicinity if anomalies be taken into account. For quantitative studies, actual mean or average data on the basin should, of course, be taken.

The fact that the phase of the Brückner cycle in both temperature and rainfall may differ in different parts of the country or world, explains very nicely just why

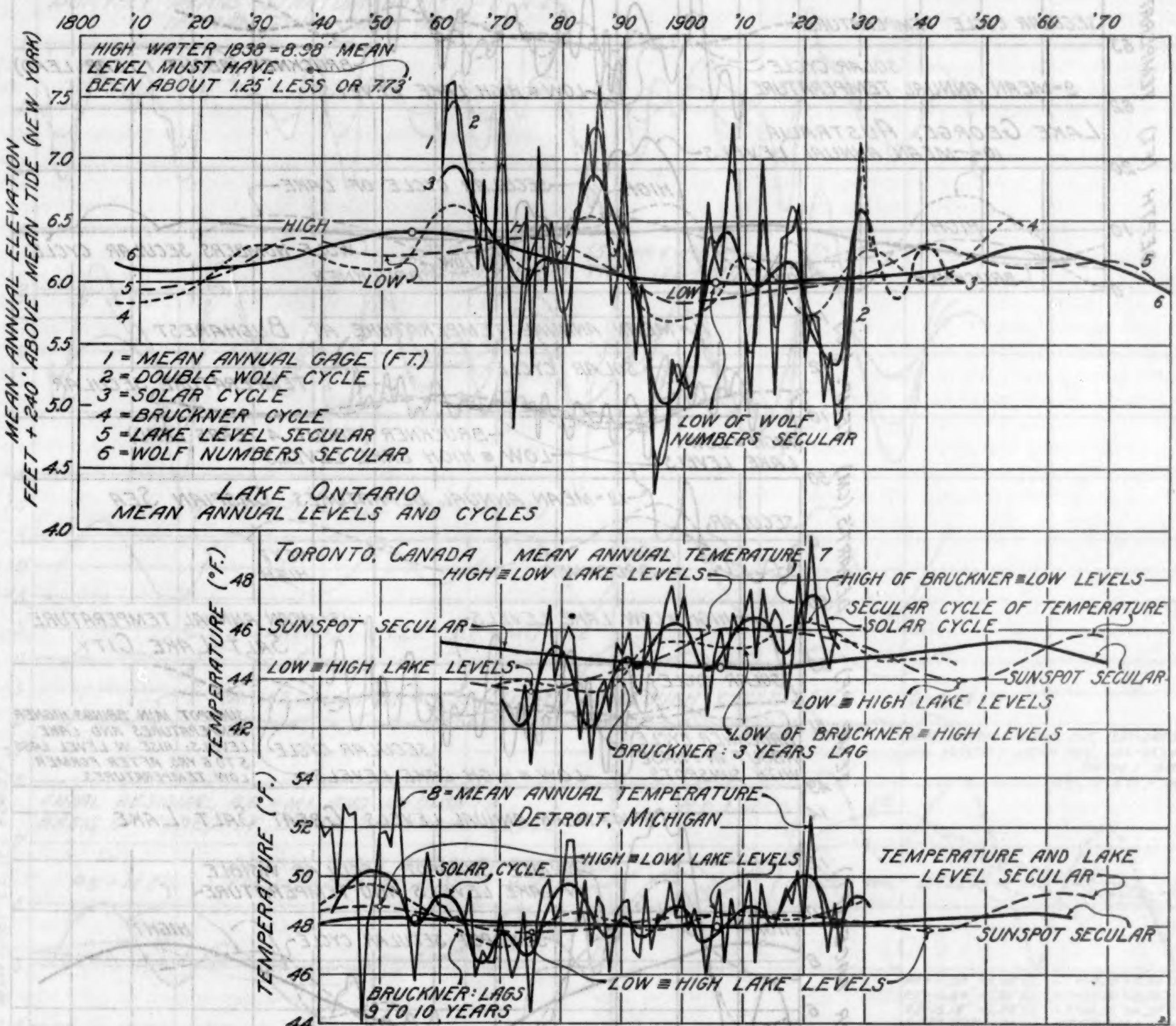

FIGURE 4.—Lake Ontario levels and cycles. Comparing the Toronto curve with that of Detroit, the Brückner cycle in former lags three years and in the latter lags nine years behind sun-spots trend, yet the secular cycle phases are identical

Brückner found, see his Table 1, some difficulty in matching up the periods of the lake oscillations; the HIGH lake levels, occurring as the LOWS of the temperature and the HIGHS of the rainfall secular cycles combined together, the occurrence of this event differing from place to place.

increased run-off and higher lake levels during wetter than normal weather is due, according to the opinion of the writer, to the effect of temperature. It is evident that as the secular trend of the temperature of a district reaches its LOW, the evaporation from the ground and the lakes therein must diminish, and this period is

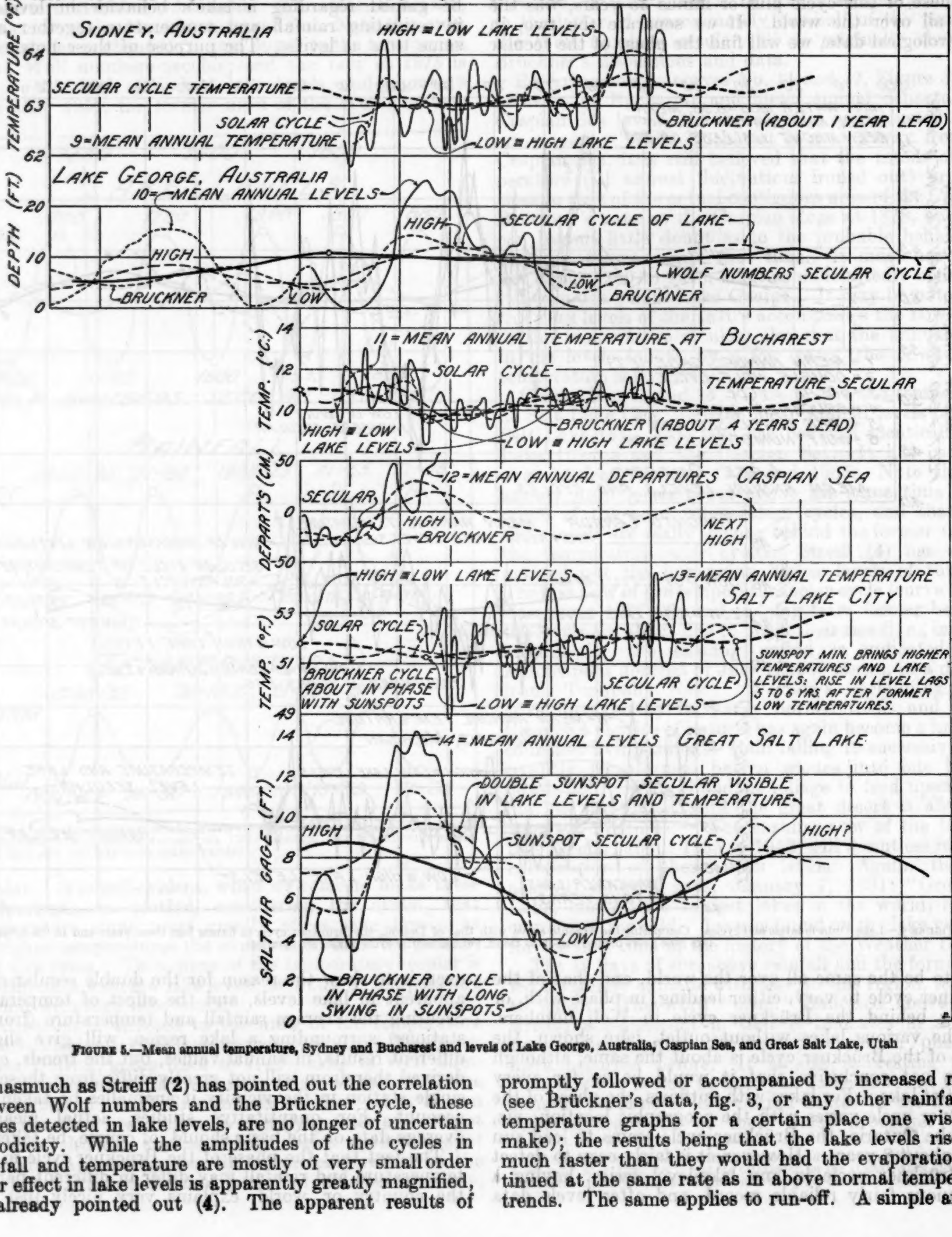

FIGURE 5.—Mean annual temperature, Sydney and Bucharest and levels of Lake George, Australia, Caspian Sea, and Great Salt Lake, Utah

Inasmuch as Streiff (2) has pointed out the correlation between Wolf numbers and the Brückner cycle, these cycles detected in lake levels, are no longer of uncertain periodicity. While the amplitudes of the cycles in rainfall and temperature are mostly of very small order their effect in lake levels is apparently greatly magnified, as already pointed out (4). The apparent results of

promptly followed or accompanied by increased rainfall (see Brückner's data, fig. 3, or any other rainfall and temperature graphs for a certain place one wishes to make); the results being that the lake levels rise very much faster than they would had the evaporation continued at the same rate as in above normal temperature trends. The same applies to run-off. A simple analogy

fits the case clearly—rainfall and temperature, in their causative effect in raising and lowering lake levels, are analogous to the motor and brakes of an automobile, the former tends to raise or drive forward, the latter tends to retard the action. It appears that at the time of increased rainfall, the "brakes" are taken off.

Knowing what to look for, in the matter of cycles, it is now comparatively easy to detect them in a record of levels, and the probable future extensions of the larger

tions, with very hot summers. The return of this lake to its former size and depth is a matter of grave concern to the citizens of that part of the State. Beach marks of former greatly higher levels are in evidence around the lake. It is quite likely that this lake will again refill, but level records are insufficient to set up with certainty the cycles. However, at the eastern end of the lake, the desiccation has continued to the extent that petrified, or alkaline coated stumps of trees are now visible.

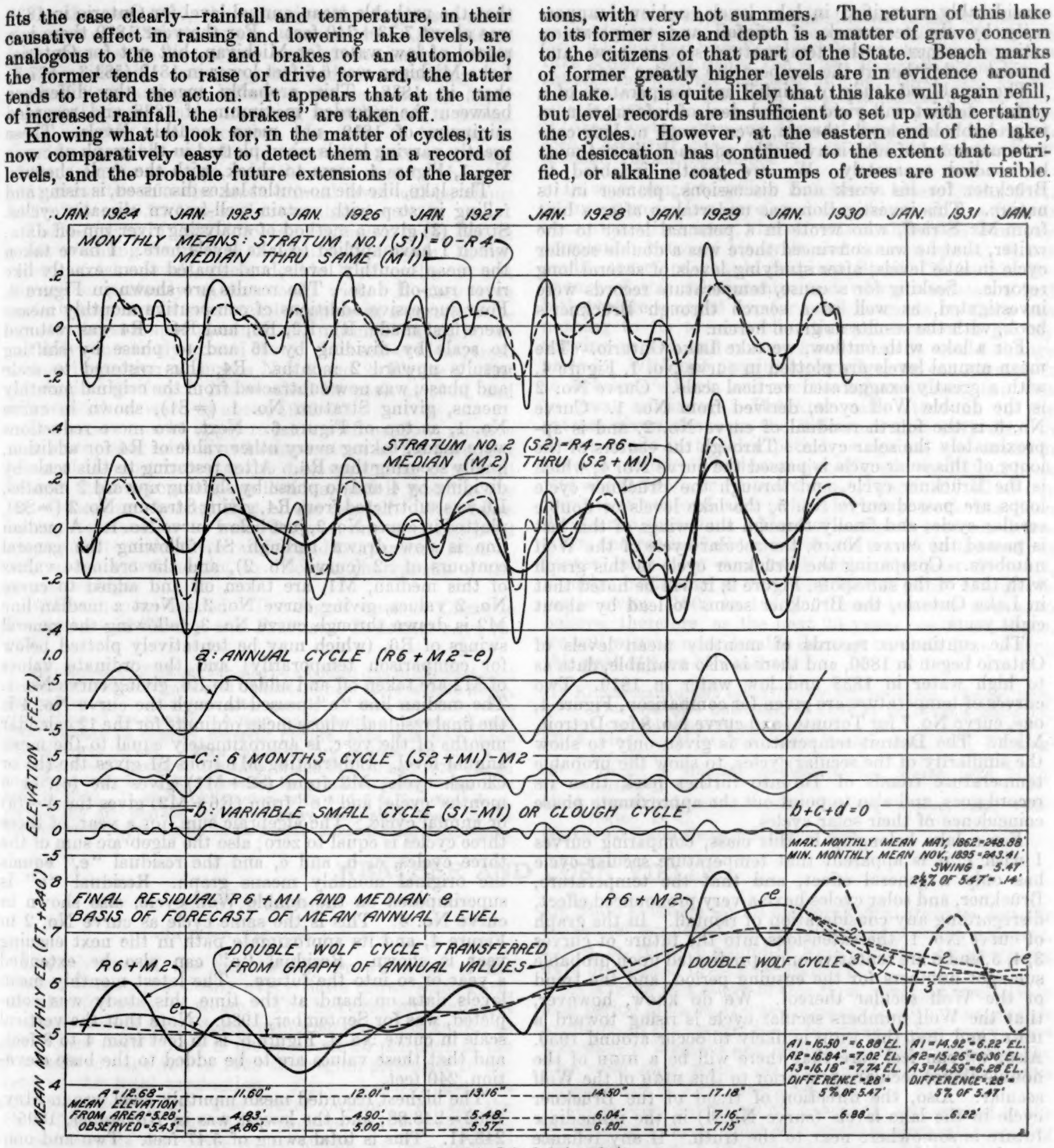

FIGURE 6.—Lake Ontario analysis

swing cycles, predicated on the probable recurrence of the Wolf numbers maxima and minima, and the trend of their secular cycle, enables us to set up a general picture of the future probable levels.

Devils Lake, N. Dak., is a no-outlet lake, and in 1867 was of considerable size and depth (111 square miles area). It has been steadily reduced in area and depth until in 1928 it has fallen 25 feet. The rainfall in this region varies from about 10.5 to 25.5 inches per year. This region is also subject to great temperature oscilla-

This indicates, beyond a doubt, that in former times, this lake was drier even than it is now, and stayed so, long enough for a good sized tree to grow.

In the foregoing, we have pointed out, that the Brückner cycle in rainfall and temperature records follows, or is in step with, a similar cycle in Wolf numbers, and that as a HIGH or LOW point in the secular swing of the Wolf numbers necessarily entails two HIGHS of the Brückner cycle, one before and one after the secular cycle turning points, there results a "double" secular cycle, which is

considerably mangified in lake levels; achieved apparently by the teamwork of rainfall and temperature, acting together at the temperature secular LOW, and against each other at the temperature secular HIGH.

The combined study of rainfall and temperature of a certain district will yield a good deal of information as to probable lake levels therein, even though no long continuous record of such is available, and each district must be studied separately. We are greatly indebted to Brückner for his work and discussions, pioneer in its nature. This investigation was undertaken after a hint from Mr. Strieff, who wrote in a personal letter to the writer, that he was convinced there was a double secular cycle in lake levels, after studying levels of several long records. Seeking for a cause, temperature records were investigated, as well as a search through Brückner's book, with the results as given herein.

For a lake with outflow, we take Lake Ontario. The mean annual levels are plotted in curve No. 1, Figure 4, with a greatly exaggerated vertical scale. Curve No. 2 is the double Wolf cycle, derived from No. 1. Curve No. 3 is the fourth residual of curve No. 2, and is approximately the solar cycle. Through the centers of the loops of this solar cycle is passed the curve No. 4, which is the Brückner cycle, and through the Brückner cycle loops are passed curve No. 5, the lake levels or double secular cycle; and finally through the swings of this last is passed the curve No. 6, the secular cycle of the Wolf numbers. Comparing the Brückner cycle in this graph with that of the sun spots, Figure 2, it will be noted that in Lake Ontario, the Brückner seems to lead by about eight years.

The continuous records of monthly mean levels of Ontario began in 1860, and there is also available, data as to high water in 1838 and low water in 1819. Two curves of temperature are given for comparison, Figure 4, one, curve No. 7 for Toronto, and curve No. 8 for Detroit, Mich. The Detroit temperature is given only to show the similarity of the secular cycles, to show the probable temperature trends of Toronto further back than its record goes, and also to point out the approximate phase coincidence of their solar cycles.

For a lake belonging in this class, comparing curves 1 with 7, it is apparent that temperature secular cycle has only a general effect, and that the temperature, Brückner, and solar cycles have a very pronounced effect, disregarding any consideration of rainfall. In the graph of curve No. 1, the extensions into the future of curves 3, 4, 5, and 6 are tentative only, predicated upon probable sun-spot numbers for the ensuing period, and the trend of the Wolf secular thereof. We do know, however, that the Wolf numbers secular cycle is rising toward a HIGH, and that this HIGH is likely to occur around 1950. Also, we can feel sure that there will be a HIGH of the double (lake) secular cycle prior to this HIGH of the Wolf secular. Also, the direction of trend of the Brückner cycle in the lake levels (curve No. 4) in the immediate future is somewhere near to the truth. If any reliance can be placed upon past behavior repeating itself, in a fashion, under similar conditions of cause, it would seem as though the mean annual levels of Lake Ontario were due for an oscillating reduction (first, high, then lower, but generally downward) for a few years, then an upward trend until about 1940; the values from 1930 to 1950 being perhaps a little less than for the 1870 to 1890 period.

With reference to levels prior to 1860, there is a record of high water in 1838, at 8.98 + 240 feet. The mean level for the year seems to average, in these records, about 1.25 feet less than the maximum level for the year, so that the probable mean annual level for Ontario in 1838 was about 7.73 + 240 feet. For the year 1819 there is a record of low water for Michigan, but not for Ontario. Lake Michigan was 6.6 feet lower in 1819 (584.3 − 577.7) than in 1838. This probably means the difference between the recorded maximum of 1838 and recorded minimum of 1819—not mean monthly levels. These greatly varying levels when plotted in the graph of curve No. 1, Figure 4, seem to check, with the cycle shown.

This lake, like the no-outlet lakes discussed, is rising and falling in step with certain well-known climatic cycles. Streiff (3) gives a method of analyzing river run-off data, which I have applied to lake levels here. I have taken the mean monthly levels, and treated them exactly like river run-off data. The results are shown in Figure 6. Four successive additions of consecutive monthly means were first made, R1, R2, R3, and R4. R4 was restored to scale by dividing by 16 and to phase by shifting results upward 2 months. R4, thus restored to scale and phase, was now subtracted from the original monthly means, giving Stratum No. 1 (=S1), shown in curve No. 1, at top of Figure 6. Next, two more reductions were made, taking every other value of R4 for addition, finally securing thus R6. After restoring to this scale by dividing by 4 and to phase by shifting upward 2 months, R6 was subtracted from R4, giving Stratum No. 2 (=S2), plotted in curve No. 2, just below curve No. 1. A median line is now drawn through S1, following the general contours of S2 (curve No. 2), and the ordinate values of this median, M1, are taken off and added to curve No. 2 values, giving curve No. 3. Next a median line M2 is drawn through curve No. 3, following the general swings of R6, (which may be tentatively plotted below for comparison temporarily) and the ordinate values of M2 are taken off and added to R6, giving curve No. 4. The median line "e" passed through the curve No. 4 is the final residual, whose mean ordinate for the 12 calendar months of the year, is approximately equal to the mean annual level. Subtracting M1 from S1 gives the (b) or Clough cycle; M2 from (S2 + M1) gives the (c), or 6 months' cycle; and "e" from (R6 + M2) gives the A = (a) or annual cycle. The algebraic sum, for a year, of these three cycles is equal to zero; also the algebraic sum of the three cycles, a, b, and c, and the residual "e," equals the original monthly means graph. Residual "e" is superimposed on the double Wolf cycle, also shown in curve No. 4. This is the same cycle as curve No. 2 in Figure 4, and its approximate path in the next ensuing year is shown. Residual "e" can also be extended a year or so into the future. The latest monthly mean levels data on hand at the time this study was completed, was for September, 1930. Note that the vertical scale in curve No. 4, Figure 6, is in feet from 4 to 8 feet, and that these values are to be added to the base elevation, 240 feet.

The highest recorded mean monthly level was in May, 1862 = 248.88; and the lowest was in November, 1895 = 243.41. This is total swing of 5.47 feet. Two and one-half per cent of this amount is equal to 0.14 feet. In extending residual "e" through to the end of 1930, I have shown three possible extensions; No. 1 is the base, for forecast values, No. 2 will give 2½ per cent greater elevation and No. 3 will give 2½ per cent less elevation, than for the base value. Residual "e" is shown plotted only from 1924 to date. The area, A, under the residual, and between January to January ordinates and zero below, is shown for each year; also the equivalent mean level, and the observed level. For all practical purposes, the computed and the observed values are the same.

For the year 1930, the extension No. 1, gives a mean elevation of 6.88 feet, for the year, or 240+6.88=246.88 feet. Extensions Nos. 2 and 3 are given simply to show that considerable error may be made in extending this residual "e," and yet influence the results only 5 per cent of the total maximum swing from highest to lowest mean monthly levels recorded. In order to forecast as closely as possible, one should secure the data to the end of the calendar year; as it is, the extension for the year 1931 indicates that the mean annual level will be about 6.22+240=246.22 feet, still lower than for 1930.

The accuracy of these forecasts depends a great deal in predetermining the path of the double Wolf cycle. In this record of lake levels, these double Wolf cycles do not emerge as perfectly as one could wish. If they were perfect, they would consistently appear in a certain relation to the sun spot maxima and minima. As it is, we can only tentatively extend them. If is self-evident, from a close inspection of curves Nos. 1 and 2, Figure 4, that the double Wolf cycle has reached its peak at 1929, and will trend downward to about 1932–33.

The same remarks apply to lakes with outflow, relative to investigating rainfall and temperature as for no-outlet lakes. It is most important to discover the lag of rainfall behind the temperature oscillations, and if possible the lag of the levels behind that of the rainfall. With lakes having data similar to Lake Ontario, one does not need necessarily to make these rainfall and temperature studies, only as indicated herein, to discover the epochs of the secular swings.

In his chapter headed "The Significance of Climatic Oscillations in Theory and Practise," Brückner says (p. 274).

Our climatic oscillations can also be modified due to different land conditions. Especially in arid districts, where there is little water, the hydrographic conditions alter greatly, in that they follow the oscillations of the rainfall. A map made during a dry period, will often present an entirely different picture, than if it were made during a wet period. Lakes vanish in dry periods and return in wet; viz, Lake George in Australia, which in 1820 and 1876 was an important lake 20 to 30 kilometers long, and an insignificant lake only in 1850. It was 10 kilometers wide and 5 to 8 meters deep, and in the dry periods, dwindled away completely down to the ground, so that grass grew in its basin. Likewise the neighboring lakes, Cowal and Bathurst, became depleted in the dry periods, and refilled in the wet periods. From a full consideration of these facts, it is clear that lakes Cowal and George behave somewhat like Lake Zurich. Very similar also is lake Hamun-Sumpf of Persia, although this does not completely dry up. Great, also, are the oscillations of Great Salt Lake, whose area changed from its minimum in 1850 to its maximum in 1870 a full 17 per cent, like that of Lake di Fucino, whose area decreased 19.2 per cent from 1816 to 1835. Relatively small, although very definite, are the larger oscillations of the Caspian Sea.

In an attempt to utilize Brückner's ideas, in the past, so many anomalies developed that his work has lain in obscurity. Brückner, himself, was unable to discover any correlation between his cycle and the sun spots. Great credit, therefore, should be given Streiff (2) for his discovery of this relationship, and why its existence had hithertofore escaped us; for until he made it, there was nothing to tie to—our climatic cycle was of a greatly varying period, and no one knew when it would change or end. With out present knowledge, we can turn back to Brückner's book, and use the information it contains to great advantage. Brückner calls attentoin in the extract given above to the difference that may exist in a map made in the dry period as against one made in the wet period. The last major climatic oscillation peak was about 1856, or 74 years ago. Practically all of our important railroad and public highway work has been done since that time. Most of our park systems driveways, and roads of all types for auto travel, in the various States, have been completed within the past 30 years, namely, beginning at the very lowest point of our climatic swing (1900 to 1910). There is every reason to believe, therefore, as the next 20 years comes on apace, we will witness considerable damage to work done during this past régime of weather.

(1) Klimaschankungen seit 1700, by Ed. Brückner, Vienna, 1890. This was also published as Heft II in Penck's Band IV, Geographische Abhandlungen.

(2) A. Streiff in Monthly Weather Review, July, 1926, Washington, D. C.

(3) A. Streiff in Monthly Weather Review, March, 1928, Washington, D. C.

(4) A. Streiff in Monthly Weather Review, October, 1929, Washington, D. C.

(5) United States Geological Survey data.

WEATHER AND CORN YIELDS

By W. A. MATTICE

[Weather Bureau, Washington, April, 1931]

Corn is one of the most widely grown crops of the United States; practically every State grows some corn, whether for grain or silage. The heaviest production is concentrated in nine States, comprising what is known as the "Corn Belt"; here is found about 60 per cent of the Nation's acreage and in 1925 this region produced 70 per cent of the total production. Figure 1 shows the area under consideration. The States outlined contain the Corn Belt proper, but the sections of heavy production do not include the entire region shown, as it is confined to the central parts of the Ohio Valley States, most of Iowa and Missouri, southeastern Minnesota and South Dakota, and eastern Kansas and Nebraska. The figures shown in the State boundaries are the percentages of the total crop area that is planted to corn in each State.

The weather data used in this study were obtained from the State Section Summaries and the original records of observations on file at the central office of the Weather Bureau. The precipitation and mean temperature data are State averages for all meteorological stations, but the maximum temperatures, percentage of possible sunshine, and p. m. relative humidity were obtained by averaging data of selected first-order stations.

As is usual in a study of this type, covering a relatively long period of years, it was necessary to adjust the records available to the several State boundaries, but every effort was made to keep the data representative and comparable. The yield data were obtained from the United States Department of Agriculture reports.

The method developed by Kincer (2) was applied to the several State data, using five weather elements covering the period April 1 to September 30, inclusive. In order to conserve space, and also as the method is familiar to most of the readers of this publication, the various data used in computation of the bases are omitted and only the final computed yields are given. By the expression "bases" is to be understood the computed yields used as a weather index for subsequent calculations. That expression is used for brevity and convenience in discussion. Table 1 shows the actual corn yields in bushels per acre and Table 2 the computed bases; the averages for the

section are also given. The subsequent tabulation gives the data used in computation of the final bases and the equations derived therefrom.

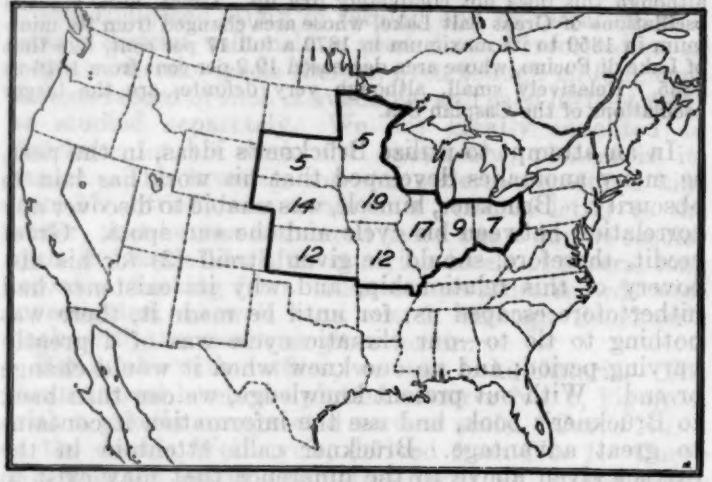

FIGURE 1.—The Corn Belt States. Region outlined shows the area of heaviest production. This area in 1925 grew 59 per cent of the total corn crop of the United States. Figures within State boundaries indicate per cent of total acreage planted to corn in the respective States

A word of explanation is necessary at this point. The weather variables for Ohio were so numerous that the computation of a straight multiple equation was avoided, the data being first combined in groups of three variables

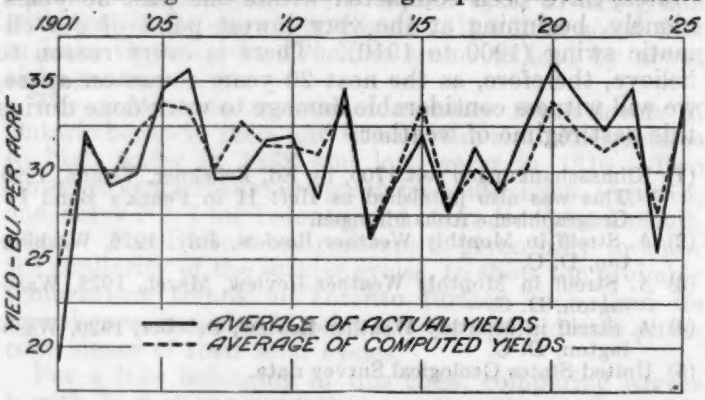

FIGURE 2.—Computed and actual yields of corn, bushels per acre, for the Corn Belt. Arithmetic average of individual State bases

and a final equation computed from them. Thus, this State has three preliminary equations, the results being combined in the final, or fourth, expression.

TABLE 1.—*Yields of corn, bushels per acre*

Years	Ohio	Indiana	Illinois	Minnesota	Iowa	Missouri	South Dakota	Nebraska	Kansas	Average
1901	26.1	19.8	21.4	26.3	25.0	10.1	21.0	14.1	7.8	19.1
1902	38.0	37.9	38.7	22.8	32.0	39.0	18.9	32.3	29.9	32.2
1903	29.6	33.2	32.2	28.3	28.0	32.4	27.2	26.0	25.6	29.2
1904	32.5	31.5	36.5	26.9	32.6	26.2	28.1	32.8	20.9	29.8
1905	37.8	40.7	39.8	32.5	34.8	33.8	31.8	32.8	27.7	34.6
1906	42.6	39.6	36.1	33.6	30.5	32.3	33.5	34.1	28.9	35.6
1907	34.6	36.0	36.0	27.0	29.5	31.0	25.5	24.0	22.1	29.5
1908	38.5	30.3	31.6	29.0	31.7	27.0	29.7	27.0	22.0	29.6
1909	39.5	40.0	35.9	34.8	31.5	26.4	31.7	24.8	19.9	31.6
1910	36.5	39.3	39.1	32.7	36.3	33.0	25.0	25.8	19.0	31.9
1911	38.6	36.0	33.0	33.7	31.0	26.0	22.0	21.0	14.5	28.4
1912	42.8	40.3	40.0	34.5	43.0	32.0	30.6	24.0	23.0	34.5
1913	37.5	36.0	27.0	40.0	34.0	17.5	25.5	15.0	3.2	26.2
1914	39.1	33.0	29.0	35.0	38.0	22.0	26.0	24.5	18.5	29.5
1915	41.5	38.0	36.0	23.0	30.0	29.5	29.0	30.0	31.0	32.0
1916	31.5	34.0	29.5	33.5	36.5	19.5	28.5	26.0	10.0	27.7
1917	38.0	36.0	38.0	30.0	37.0	35.0	28.0	27.0	13.0	31.3
1918	36.0	33.0	35.5	40.0	36.0	20.0	34.0	17.7	7.1	28.8
1919	43.0	37.0	36.0	40.0	41.6	27.0	28.5	26.2	15.2	32.6
1920	43.4	40.5	34.6	37.5	46.0	32.0	30.0	33.8	26.5	37.0
1921	41.0	36.0	34.0	41.0	42.0	30.0	32.0	28.0	22.2	34.0
1922	39.0	37.0	35.5	33.0	45.0	28.5	28.5	25.0	19.3	32.3
1923	41.0	38.5	37.5	36.0	40.5	30.0	34.5	33.0	21.7	34.7
1924	26.0	25.6	33.0	27.0	28.0	24.0	21.3	22.0	21.7	25.4
1925	48.0	43.5	42.0	36.0	43.9	29.5	17.5	26.0	16.6	33.7
Mean	37.7	35.7	34.7	32.6	35.7	27.7	27.5	26.1	19.5	30.8
σ	5.21	5.00	4.44	5.14	5.73	6.16	4.52	5.35	7.12	3.68

TABLE 2.—*Computed yields of corn, bushels per acre*

Years	Ohio	Indiana	Illinois	Minnesota	Iowa	Missouri	South Dakota	Nebraska	Kansas	Average
1901	34.0	26.1	26.9	32.9	35.5	16.2	23.6	15.9	9.5	24.5
1902	34.8	36.0	42.6	26.2	30.2	31.1	25.3	29.9	28.4	31.6
1903	30.9	34.9	34.3	26.8	31.4	30.4	27.6	21.2	28.0	29.5
1904	35.8	32.6	37.7	25.2	38.7	33.3	26.5	31.6	28.3	32.2
1905	37.9	37.3	40.1	34.6	33.5	31.3	33.2	30.1	25.1	33.7
1906	46.3	37.4	31.5	28.9	40.5	29.9	29.9	29.6	26.4	33.4
1907	34.6	36.9	35.2	29.7	31.4	30.2	27.6	23.5	21.6	30.1
1908	41.0	34.3	34.8	31.4	33.7	30.8	31.2	30.3	26.4	32.7
1909	37.3	38.4	34.4	35.3	34.9	26.3	28.9	28.3	19.8	31.3
1910	36.1	41.1	35.5	35.8	32.1	31.8	21.4	25.0	23.3	31.3
1911	37.5	37.6	34.0	37.0	39.4	27.9	22.3	23.8	18.0	30.8
1912	44.8	41.8	39.4	30.8	39.8	29.5	28.9	27.2	20.2	33.6
1913	38.0	35.4	30.2	37.9	34.3	18.4	24.0	15.4	3.2	26.3
1914	37.4	33.5	28.5	34.3	36.7	24.6	27.3	25.7	18.4	29.6
1915	42.5	41.7	35.1	21.3	28.6	38.6	30.1	33.4	31.5	33.6
1916	29.8	31.8	29.5	31.1	35.8	22.3	29.8	24.3	12.0	27.4
1917	34.0	33.0	37.6	31.4	36.8	31.4	26.8	25.9	12.7	30.0
1918	36.4	33.6	36.7	34.4	30.4	21.6	33.4	24.0	9.8	28.9
1919	38.7	30.7	31.7	37.0	40.3	26.4	27.6	24.1	15.3	30.2
1920	38.9	38.1	33.1	36.1	40.4	32.0	34.1	31.7	20.8	33.9
1921	41.1	36.5	35.7	37.9	38.6	26.4	28.1	22.6	21.6	32.1
1922	38.3	37.6	32.5	35.5	41.0	27.5	28.5	21.1	19.1	31.2
1923	39.5	34.2	35.9	34.3	34.8	28.6	27.9	34.1	19.3	32.1
1924	30.0	28.0	34.2	29.1	28.4	31.3	21.9	27.5	18.5	27.7
1925	46.8	43.6	38.9	35.9	43.1	27.5	23.4	24.1	16.1	33.3
Mean	37.7	35.7	34.6	32.4	35.6	28.2	27.6	25.9	19.7	30.8
σ	4.38	4.06	3.64	4.27	4.12	4.74	3.43	4.69	6.69	2.42
Sxy	2.81	2.76	2.52	2.93	4.06	3.90	2.94	3.09	2.76	......
rx	+.84	+.83	+.82	+.82	+.71	+.78	+.76	+.82	+.92	+.89

Ohio.—Equations and variables used.

$$X_1=0.781A-0.489M+1.032B-50.335 \quad (1)$$

$$X_2=-0.595E+0.401K+0.552C+17.755 \quad (2)$$

$$X_3=0.259G+1.744D+0.347F-12.827 \quad (3)$$

$$\bar{X}=0.589X_1+0.413X_2+0.297X_3-11.290 \quad (4)$$

A = Mean temperature, September.
B = Mean temperature, June.
C = Mean maximum temperature, April.
D = Total precipitation, July.
E = P. m. relative humidity, June.
F = Mean maximum temperatures, September.
G = Percentage of possible sunshine, June.
K = P. m. relative humidity, August.
M = Percentage of possible sunshine, July.

Indiana.—Equation and variables used.

$$\bar{X}=2.646A+0.234L+0.433H+0.559D-22.990$$

A = Total precipitation, July.
L = Percentage of possible sunshine, May.
H = Mean maximum temperatures, September.
D = Total precipitation, September.

Illinois.—Equation and variables used.

$$\bar{X}=0.476A-0.412F+1.230K-0.603G-0.722E-0.438J+110.907$$

A = P. m. relative humidity, July.
F = Percentage of possible sunshine, September.
K = Total precipitation, April.
G = Mean maximum temperatures, August.
E = Total precipitation, July.
J = P. m. relative humidity, September.

Minnesota.—Equation and variables used.

$$\bar{X}=0.622A+0.526C+0.154F-0.441I-0.333M-16.187$$

A = Mean temperature, June.
C = Mean maximum temperatures, August.
F = Percentage of possible sunshine, July.
I = P. m. relative humidity, April.
M = Percentage of possible sunshine, April.

Iowa.—Equation and variables used.

$$\bar{X}=0.912A+1.734D-1.122F-0.558I+0.543J+0.130L-30.656$$

A = Mean temperature, September.
D = Total precipitation, April.
F = Total precipitation, May.
I = Mean temperature June.
J = Mean maximum temperatures, May.
L = Percentage of possible sunshine, June.

Missouri.—Equation and variables used.

$$\overline{X} = -0.894B - 723C + 169.102$$

B= Mean maximum temperatures, August.
C= Mean maximum temperatures, July.

South Dakota.—Equation and variables used.

$$\overline{X} = 1.737A + 0.291B + 1.496K + 0.143F + 0.078H - 8.866$$

A= Total precipitation, May.
B= P. m. relative humidity, July.
K= Total precipitation, April.
F= Percentage of possible sunshine, May.
H= Percentage of possible sunshine, September.

Nebraska.—Equation and variables used.

$$\overline{X} = 0.638A - 0.504E - 1.191D - 3.373L + 0.593H + 0.270J + 63.808$$

A= P. m. relative humidity, August.
E= Percentage of possible sunshine, June.
D= Mean temperature, July.
L= Total precipitation, July.
H= Mean maximum temperatures, June.
J= P. m. relative humidity, July.

Kansas.—Equation and variables used.

$$\overline{X} = 0.399A + 0.430B + 0.245O + 0.177L - 45.981$$

A= P. m. relative humidity, August.
B= P. m. relative humidity, July.
O= P. m. relative humidity, May.
L= P. m. relative humidity, September.

One striking feature that is instantly apparent is the fact that every variable in Kansas is relative humidity; this item appears more important in the Plains than elsewhere. Undoubtedly, the relative humidity at the p. m. observation is a fairly good index of the weather conditions as affecting corn, at least in the Plains States. The moisture conditions are more precarious here than farther east, and anything which tends to increase evaporation, would necessarily produce its effect on crops. Evaporation and relative humidity are closely related, so the latter produces an indirect effect on yields through that relation.

The coefficients of correlation, as shown in Table 2, are all fairly high, ranging from 0.71 for Iowa to 0.92 for Kansas. Iowa has always been a rather difficult State for which to correlate corn yields and weather, so the low coefficient there was not surprising. Kansas, on the other hand, has been a favorable one for correlation purposes. One item shown in Table 2, the standard error of estimate, Sxy, needs some explanation. The value shown is derived in the same manner as standard deviation, except that the departures are computed from actual and computed yields. The standard error, compared with the standard deviation of yield, shows the value of the coefficient of correlation instantly, for if the standard error is not sufficiently smaller than the standard deviation, the coefficient is valueless. It might be added that in order to reduce the standard error to 50 per cent of the standard deviation it is necessary to have a coefficient between 0.86 and 0.87.

Figure 2 shows the actual and computed yields of corn in bushels per acre for the Corn Belt as a whole. The two sets of data were obtained by averaging the yields for the nine States. The agreement is very close, except for 1901. The coefficient of correlation between these values is 0.89, a value sufficiently high to justify the statement that yields are largely dependent on the weather, and that we have included the major items necessary.

WEIGHTED CORRELATIONS

It is realized, of course, that the method of obtaining the final computed yields for the Corn Belt as a whole, is open to question, as the method of weighting each State equally would be considered erroneous by some authorities. It was with this thought in mind that the entire ground was again covered in a different manner.

The various States appeared to lend themselves readily to a grouping by sections, as follows: The Ohio Valley, the Mississippi Valley, and the Great Plains. The Ohio Valley States were Ohio, Indiana, and Illinois. The Mississippi Valley States were originally intended to be Minnesota, Iowa, and Missouri, but in examining the coefficients it was found that Missouri did not correlate with the others, in fact, when Minnesota and Iowa had positive coefficients with a certain weather variable, Missouri was negative, etc. Therefore, it was decided to combine only Minnesota and Iowa in the Mississippi Valley and include Missouri in the Great Plains as it correlated with the latter area.

The final grouping of the Great Plains then became: South Dakota, Nebraska, Kansas, and Missouri. The disagreement of Missouri is very interesting, as it indicates that Missouri weather resembles that of the Plains more than that of the Mississippi Valley.

The weights were found by computing the per cent each State acreage was of the total for the group. Thus, the per cent of corn acreage of Ohio was obtained by dividing the acreage of corn in Ohio by the acreage of the Ohio Valley group. This percentage was obtained for each year of the 25 studied, for as the acreage varied, so the weight that should be given to an individual item should vary. The yields were weighted by multiplying each yield figure by its corresponding percentage, then obtaining the sum of the results. Thus, there was obtained a final yield figure that was weighted directly by the importance of the several States.

The selection of the variables to be used was somewhat more complex. As a preliminary step the coefficients of correlation of each State for the five weather items were entered in a table. It was then possible to pick out those months of greatest importance as the coefficients would all be of the same sign, although of various magnitudes. The selected values were then weighted in the same manner as the yields and the coefficients of correlation obtained. From this step on the method is exactly the same as before, so a detailed discussion is not necessary. The equations and variables used are given below.

The Ohio Valley.—Equation and variables used.

$$\overline{X} = 0.575A + 0.745F - 0.658E - 1.161B + 0.180H - 6.450$$

A= P. m. relative humidity, July.
B= Total precipitation, July.
E= Mean temperature, July.
F= Mean temperature, September.
H= P. m. relative humidity, September.

The Mississippi Valley.—Equation and variables used.

$$\overline{X} = 0.643A + 0.177C + 1.784D + 0.115K - 28.043$$

A= Mean temperature, September.
C= Percentage of possible sunshine, May.
D= Total precipitation, April.
K= Percentage of possible sunshine, June.

The Great Plains and Missouri.—Equation and variables used.

$$\overline{X} = 0.433A + 0.258B - 0.661C + 0.205N + 0.341O + 8.881$$

A= P. m. relative humidity, August.
B= P. m. relative humidity, July.

C=Mean maximum temperatures, July.
N=P. m. relative humidity, May.
O=Percentage of possible sunshine, July.

P. m. relative humidity is still of greatest importance in the Great Plains, but elsewhere there is a wider range of the variables.

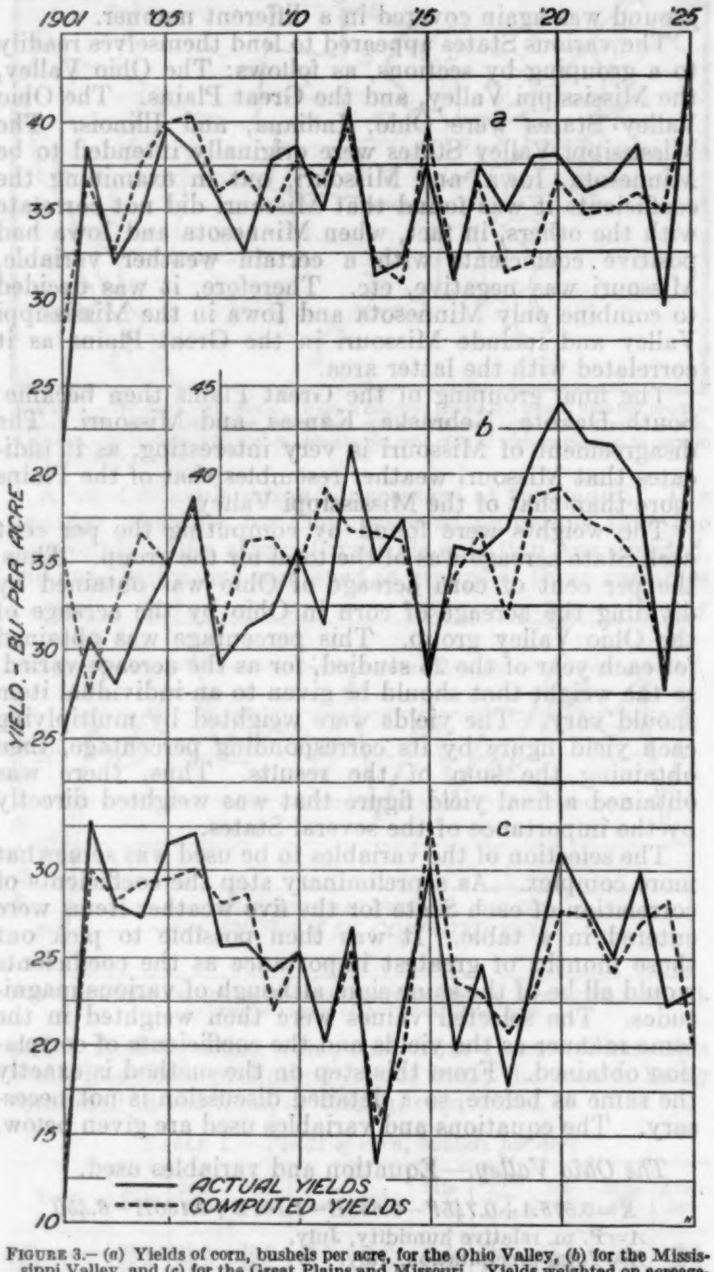

FIGURE 3.—(a) Yields of corn, bushels per acre, for the Ohio Valley, (b) for the Mississippi Valley, and (c) for the Great Plains and Missouri. Yields weighted on acreage-percentage basis

Figure 3 shows the computed and actual yields for these three divisions, "a" being that for the Ohio Valley, "b" that for the Mississippi Valley, and "c" that for the Great Plains and Missouri. The final bases and yields are also given in Table 3. The Great Plains again agrees more closely with actual yields than the others, with a coefficient of 0.88, while the Mississippi Valley coefficient was only 0.63.

TABLE 3.—*Computed and actual yields of corn for the three divisions of the Corn Belt*

Years	The Ohio Valley		The Mississippi Valley		The Great Plains and Missouri	
	Computed	Actual	Computed	Actual	Computed	Actual
1901	28.0	21.9	35.2	25.2	12.8	11.3
1902	36.6	38.4	27.7	30.7	29.9	32.6
1903	32.6	32.0	32.4	28.0	28.0	27.9
1904	37.5	34.4	36.6	31.8	29.2	27.2
1905	39.9	39.7	34.9	34.5	29.4	31.4
1906	40.3	38.3	37.7	38.7	30.0	32.0
1907	36.1	35.7	30.9	29.1	28.2	25.7
1908	37.2	32.7	36.1	31.3	28.6	25.8
1909	34.9	37.7	36.4	32.1	22.1	24.3
1910	37.7	38.6	34.4	35.7	25.4	25.4
1911	36.6	35.0	39.2	31.5	20.3	20.3
1912	39.5	40.7	36.7	41.5	25.3	26.8
1913	32.0	31.3	36.6	35.1	15.6	13.4
1914	30.8	32.0	36.1	37.4	19.9	22.4
1915	39.5	37.6	29.3	28.5	32.6	30.1
1916	31.3	31.1	34.3	35.8	23.7	19.9
1917	36.5	37.4	36.6	35.5	23.0	24.6
1918	31.4	34.9	31.8	36.9	20.8	17.8
1919	32.0	37.9	38.7	41.2	23.2	24.5
1920	36.6	38.0	39.2	44.0	27.7	31.0
1921	34.7	36.0	37.4	41.8	27.4	28.1
1922	35.0	36.7	36.7	41.6	24.3	25.2
1923	35.9	38.6	34.8	39.3	27.0	29.9
1924	34.8	29.6	28.9	27.7	28.3	22.3
1925	41.6	43.7	40.2	41.7	20.2	23.2
σ	35.6	35.6	35.2	35.1	24.9	24.9
Mean	3.32	4.31	3.25	5.21	4.68	5.30
rx	+.77		+.63		+.88	

In combining these three divisions to make a final computation for the entire area, two methods were used. First, a simple arithmetic average, and second, by weighting on an acreage-percentage basis. The acreages for the several divisions were divided by the total for the belt and the yearly percentages obtained. The coefficients of correlation were, respectively, for the weighted and unweighted values, 0.83 and 0.78. Figure 4 shows the

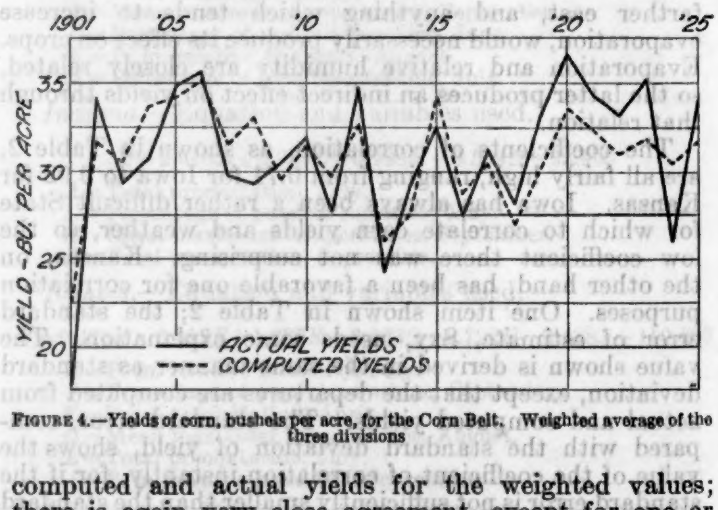

FIGURE 4.—Yields of corn, bushels per acre, for the Corn Belt. Weighted average of the three divisions

computed and actual yields for the weighted values; there is again very close agreement, except for one or two years.

In order to give the weighting method a further test, it was decided to weight the original final bases for the individual States, obtained as before indicated. The percentage of acreage in each State was computed, based on the acreage of the entire region, and these percentages applied to the final bases. The computed yields thus obtained were compared with the actual figures, also

weighted, and the final coefficient of correlation was 0.90. This small increase over the original method is very important, as there is an increased reduction of standard deviation of about 2 per cent.

The yields computed in this manner agree a little more closely in those years which were at variance before, thus making this method a little better than the other one. The actual and computed yields are shown in figure 5.

Thus, we have two methods of computing corn yields in the belt. The method of weighting seems to be of slightly more value than that of simple arithmetic averages. The weighting of individual weather items in correlating weather and corn yields does not return as high a coefficient as considering each State individually and then weighting to its proper place in the belt.

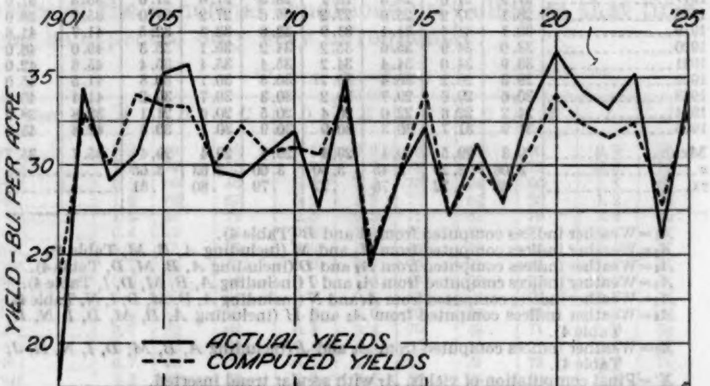

FIGURE 5.—Yields of corn, bushels per acre, for the Corn Belt. Weighted average of individual State bases

THE STATE OF IOWA

In Iowa "Corn is King." The corn crop is to this State what cotton is to the South. It follows, therefore, that any factor that affects the size of the corn crop is of vital interest not only to the State, but to the Nation. The weather is, naturally, the most important element influencing the growth of corn and this paper will attempt to show those periods of most importance.

The average corn production in Iowa for the years 1921–1925 was 426,000,000 bushels, or about 15 per cent of the average of the whole country for the same period. It will be seen, therefore, that the Iowa corn crop is of great importance, and many investigators have studied the effect of weather on the yields of corn in this State, but none in such detail as Wallace (1).

Wallace said, in part:

> In Iowa the multiple coefficient of correlation between yield and May temperature, July temperature, and August rain is disappointingly low * * * superficial examination of the evidence leads to the conclusion that the low correlation coefficient in Iowa is due to the fact that in Iowa there are some seasons and some sections when the yield is short because of the too cool weather during the greater part of the summer, whereas in other years the yield is short because of too hot weather. * * * Obviously, therefore, the method of correlation coefficients is not very well adapted to examining the effect of weather on corn yield in Iowa.

With this conclusion there was set forth a series of tables, based on correlation coefficients, from which could be computed the percentage the crop would be above or below an average determined from a line of secular trend. This was done for two counties, one in the northern and one in the central part of the State, with the main work on Polk County crops. While this method of computing yields is sometimes very satisfactory, it can not be said that it has a strict mathematical foundation, therefore it was decided to apply Kincer's method (2) to the yield and weather data of Iowa.

In a study of this type, based on average yields for a whole State, the stations chosen for the weather data must be well distributed and fairly representative of conditions over the whole section. There are, of course, periods when a complete distribution is difficult to obtain and for such cases the best data available may not completely satisfy the necessary requirements. Iowa is fairly well covered by a network of cooperative stations and the weekly precipitation data are based on the entire number, computed from the climatological records. The regular Weather Bureau stations, of course, do not fully cover the State, but for such data as sunshine, and mean and maximum temperatures they are believed to be adequate. Four stations were chosen for the temperature factor, Dubuque, Des Moines, Charles City, and Sioux City, covering fairly well the section of heaviest production.

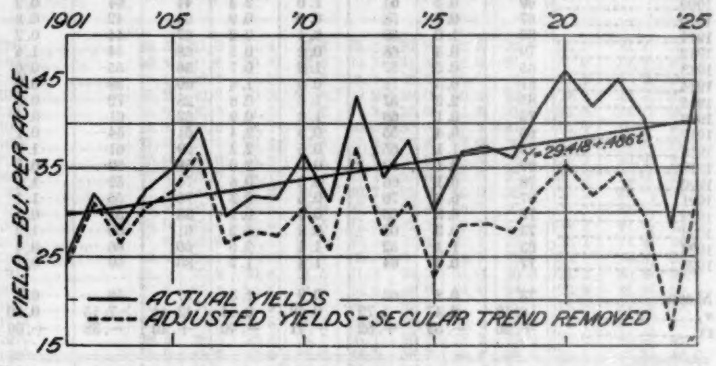

FIGURE 6.—Yields of corn, bushels per acre, for the State of Iowa. Upper solid line shows observed yields, lower broken line shows the adjusted yields after removal of secular trend. Line of secular trend is also shown

The period 1901–1925 was chosen for study as nearly complete records were available for the 25 years. An extension of the time backward or forward might be effected, but records become more fragmentary in the earlier years and less ready of access in the later ones.

It was found that the secular trend of corn yields in this period increased at the rate of about 0.5 bushel per year, the complete equation being $y=29.418+0.486t$, where t is the time in years. Wallace had found an annual increase of 0.25 bushel in the Iowa data from 1891 to 1919 and Reed (3) found an increase of 0.283 bushel per year in the years 1890–1926. It would seem, therefore that the period, 1901–1925 was that of greatest increase in yield. Reed's conclusions as to the upward trend are very pertinent to this study and will bear repeating:

> There is a well-defined tendency for corn in Iowa to become more and more damaged by frost before it reaches maturity. * * * This scarcely leaves a doubt that the farmers of Iowa by breeding for large yields per acre have sacrificed maturity of the crop.

The success of this practice is well demonstrated in Figure 6, which shows the yields in bushels per acre for the period under consideration as well as the yields when secular trend has been removed. In order to remove the trend, which is obviously unrelated to weather influences, the equation mentioned above was applied to the observed yields. The annual increment was 0.486 bushel and this, multiplied by its proper value of t, was subtracted from the original data. This, as shown, removed the external influence of increased yields and permitted the application of Kincer's method.

The new yield figures can be considered as entirely separate from the original ones and handled as desired. The mean, standard deviation, etc., were computed for the new data as though it had no connection with the original. The operations performed in this paper are as described by Kincer and need no further explanation.

TABLE 4.—*Iowa*

Year	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
1901	66	1.1	57	1.3	1.4	55	62	0.9
1902	79	0.9	70	0.9	1.7	55	63	0.6
1903	78	0.4	69	1.1	0.5	46	64	1.4
1904	77	0.2	65	0.7	0.6	67	58	1.2
1905	71	0.5	60	1.1	0.6	72	65	2.6
1906	78	0.8	67	1.7	0.7	58	59	0.4
1907	66	0.6	57	1.2	2.4	33	62	0.0
1908	76	1.0	65	2.0	1.6	56	70	1.0
1909	69	0.5	61	1.0	2.3	44	64	0.2
1910	67	0.7	58	0.0	0.9	64	42	0.8
1911	80	1.0	69	0.4	0.2	67	44	0.2
1912	79	0.3	68	0.2	0.5	68	54	1.4
1913	65	0.5	57	1.0	0.7	36	55	0.6
1914	81	0.5	71	0.6	1.6	60	58	0.9
1915	65	2.3	57	1.6	0.8	28	72	0.3
1916	75	0.1	66	1.3	0.9	52	61	0.4
1917	66	0.4	55	0.6	3.4	51	54	0.1
1918	75	1.1	65	0.6	2.3	50	61	1.2
1919	69	0.1	59	0.9	2.0	58	69	0.6
1920	78	0.1	66	0.3	0.6	74	52	1.9
1921	87	0.6	76	0.5	0.3	70	55	1.1
1922	75	0.8	66	0.3	0.1	38	51	0.5
1923	73	0.3	62	0.8	1.2	61	60	1.2
1924	63	1.1	52	1.4	2.5	60	66	0.4
1925	77	0.3	64	1.4	1.7	86	59	0.1
Mean	73	0.6	63	0.9	1.3	57	59	0.8
σ	6.18	0.47	5.72	0.49	0.84	13.44	7.15	0.60
rx	+.56	−.53	+.52	−.41	−.40	+.40	−.38	+.36

Year	*I*	*J*	*K*	*L*	*M*	*N*	*O*
1901	0.3	55	0.6	63	71	0.5	63
1902	1.6	60	1.7	59	68	0.8	57
1903	0.8	74	3.5	59	69	0.0	61
1904	0.9	64	1.6	57	71	0.3	61
1905	2.0	63	0.2	65	77	1.8	68
1906	1.4	53	1.1	75	81	1.9	71
1907	1.0	78	2.1	42	78	1.2	66
1908	1.1	71	2.7	55	87	0.0	75
1909	2.1	76	1.4	46	77	0.4	69
1910	0.6	62	0.8	40	69	0.7	59
1911	0.6	46	1.0	83	81	0.8	71
1912	0.1	48	0.5	78	75	0.7	67
1913	1.4	55	1.6	76	79	1.0	64
1914	1.0	57	1.4	72	71	1.5	62
1915	0.6	68	3.5	57	74	0.2	66
1916	0.5	60	1.5	59	70	0.0	61
1917	0.8	74	1.8	46	72	0.5	62
1918	1.9	67	2.1	60	69	0.2	60
1919	0.3	74	0.2	30	80	3.0	70
1920	1.1	54	0.7	67	83	0.1	72
1921	1.0	56	1.0	69	75	2.4	67
1922	0.8	48	1.7	77	73	0.8	62
1923	1.5	70	0.1	45	69	2.0	58
1924	2.9	60	0.7	47	65	0.6	57
1925	0.5	52	0.1	84	73	1.0	65
Mean	1.1	62	1.3	60	74	0.9	65
σ	0.64	9.29	0.92	14.09	5.33	0.78	4.89
rx	−.36	−.35	−.35	+.34	+.33	+.33	+.31

A=Average weekly maximum temperatures for the week ending May 26.
B=Average weekly precipitation for the week ending July 28.
C=Average weekly mean temperatures for the week ending May 26.
D=Average weekly precipitation for the week ending June 23.
E=Average weekly precipitation for the week ending June 9.
F=Average weekly percentage of possible sunshine for the week ending May 26.
G=Average weekly p. m. relative humidity for the week ending June 23.
H=Average weekly precipitation for the week ending May 12.
I=Average weekly precipitation for the week ending June 30.
J=Average weekly p. m. relative humidity for the week ending June 9.
K=Average weekly precipitation for the week ending May 26.
L=Average weekly percentage of possible sunshine for the week ending June 9.
M=Average weekly maximum temperatures for the week ending Sept. 15.
N=Average weekly precipitation for the week ending Sept. 22.
O=Average weekly mean temperatures for the week ending Sept. 15.

Table 4 shows the variables used. It will be noted that precipitation data occur seven times, and maximum temperatures, mean temperatures, percentage of possible sunshine, and the p. m. relative humidity twice each. It is significant that precipitation should appear nearly half the number of times, for others have found that the amount of rainfall is very important to corn, especially at certain critical periods. The coefficients are not especially high, running down from 0.56 to 0.31, but their combinations are more important than single coefficients.

TABLE 5.—*Iowa*

Year	A_1	A_2	A_3	A_4	A_5	A_6	A_7	X'	X
1901	25.2	24.8	24.2	25.5	25.3	25.7	26.2	26.7	25.0
1902	30.2	29.0	28.9	28.4	28.3	28.1	28.3	29.3	32.0
1903	31.8	30.7	30.1	30.4	29.5	30.1	29.4	30.8	28.0
1904	32.3	31.6	31.7	31.8	31.1	31.4	31.2	33.1	32.6
1905	29.1	29.8	29.2	28.2	29.1	31.1	31.0	33.4	34.8
1906	30.2	31.8	29.8	29.4	30.4	29.9	30.4	33.3	39.5
1907	27.1	28.1	27.5	27.7	28.1	27.3	26.5	29.9	29.5
1908	28.8	31.7	29.0	29.0	28.2	28.5	28.1	32.0	31.7
1909	28.5	29.3	29.0	27.9	27.5	27.0	26.4	30.8	31.5
1910	27.1	26.2	28.3	28.9	28.7	28.7	28.7	33.6	36.3
1911	30.1	31.7	32.5	32.9	32.6	31.8	32.5	37.8	31.0
1912	32.5	32.7	33.8	34.7	34.3	34.7	35.2	41.0	43.0
1913	27.2	28.4	28.2	27.9	28.1	28.0	28.4	34.7	34.0
1914	32.4	31.7	32.1	32.0	32.5	32.4	32.5	39.3	38.0
1915	20.1	20.5	19.7	20.9	20.6	20.6	20.7	28.0	30.0
1916	32.0	31.1	30.0	30.7	29.8	29.3	29.4	37.2	36.5
1917	27.9	27.6	28.3	28.7	28.3	27.6	27.0	35.3	37.0
1918	28.1	27.2	28.0	27.2	26.6	27.2	27.0	35.7	36.0
1919	30.1	31.4	31.1	31.9	33.8	33.3	32.5	41.7	41.6
1920	33.0	34.9	35.6	35.2	34.2	35.1	35.3	45.0	46.0
1921	33.9	34.0	34.4	34.2	35.4	35.4	35.4	45.6	42.0
1922	29.3	29.2	30.4	30.7	30.5	30.1	30.8	41.5	45.0
1923	30.6	29.6	29.7	29.2	30.3	30.7	30.2	41.4	40.5
1924	24.2	22.6	22.0	20.4	20.5	20.6	21.1	32.8	28.0
1925	31.9	31.7	30.3	30.9	30.9	30.1	30.6	42.8	43.9
Mean	29.3	29.5	29.4	29.4	29.4	29.4	29.4	35.7	35.7
σ	3.06	3.29	3.45	3.50	3.60	3.63	3.65	------	------
rx	.68	.72	.76	.77	.79	.80	.81	------	------

A_1=Weather indices computed from *A* and *B* (Table 4).
A_2=Weather indices computed from A_1 and *M* (including *A*, *B*, *M*, Table 4).
A_3=Weather indices computed from A_2 and *D* (including *A*, *B*, *M*, *D*, Table 4).
A_4=Weather indices computed from A_3 and *I* (including *A*, *B*, *M*, *D*, *I*, Table 4).
A_5=Weather indices computed from A_4 and *N* (including *A*, *B*, *M*, *D*, *I*, *N*, Table 4).
A_6=Weather indices computed from A_5 and *H* (including *A*, *B*, *M*, *D*, *I*, *N*, *H*, Table 4).
A_7=Weather indices computed from A_6 and *J* (including *A*, *B*, *M*, *D*, *I*, *N*, *H*, *J*, Table 4).
X'=Final computation of yields, A_7 with secular trend inserted.
X=Yields of corn, bushels per acre, Iowa.

Table 5 shows the computed values of corn yields for each successive step in the operation. The base 1, or

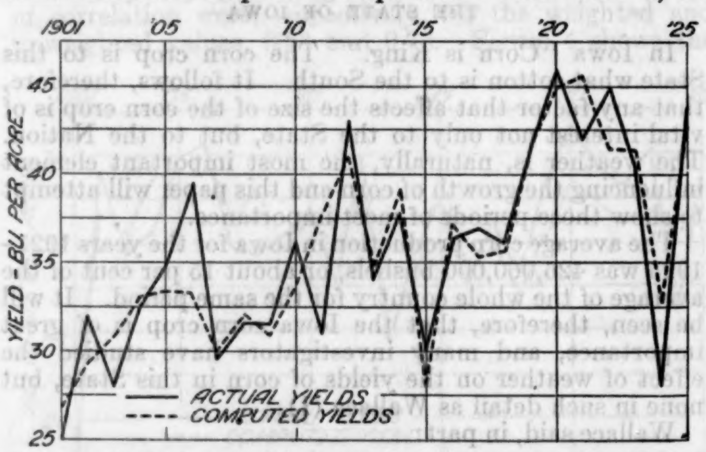

FIGURE 7.—Yields of corn, bushels per acre, for the State of Iowa. The solid line represents the actual yields and the broken line shows the computed yields

A_1, was computed from *A* and *B*, columns 1 and 2, Table 1; base A_2 was computed from A_1 and *M*, and so on up to base A_7, which concluded the series as the base A_8 did not raise the coefficient. The coefficients of correlation of these bases with corn yields increase from 0.68 to 0.81. The final base, A_7, is not adjusted as the secular trend remains to be added. This was done in the column headed X', and as column X contains the observed yields, they are directly comparable.

Figure 7 shows the computed and actual yields of corn for the years 1901–1925. There are two striking years of crop failure noted, one being in 1915 and the other in 1924. The 1915 depression is a combination of several weather influences, which are fairly well represented by the computation equation, while that in 1924 was not so well indicated as many items entered into the unfavorable conditions prevailing that season which are not repre-

sented in the equation and could not be included, under the limitations of the present data available. The season in 1924 was very late, reaching three weeks behind the average at one time, and the fall frosts cut the corn yield to a large extent. In the other years, 1906 is a conspicuous failure of the equation, but otherwise a very good relationship was obtained.

As mentioned above, the yield in 1924 was tremendously reduced; the fall frosts ended the growing season when only 32 per cent of the crop was reported fully mature, and as the average maturity at time of frost was 88 per cent, the reduction was 56 per cent, or nearly two-thirds, of the normal. The average amount of corn fit for seed was 51 per cent, but in 1924 only 16 per cent was saved. Thus, omitting 1924 from the calculations will not upset a regular sequence of years, as the recurrence of the abnormal conditions prevailing at that time can be expected only very infrequently.

TABLE 6.—*Iowa*

Year	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
1901	0.3	48	55	1.1	0.6	66	55	60	0.9	57
1902	1.4	74	55	0.9	1.7	79	60	72	0.6	70
1903	0.5	60	46	0.4	3.5	78	74	66	1.4	69
1904	1.0	66	67	0.2	1.6	77	64	70	1.2	65
1905	1.3	68	72	0.5	0.2	71	63	70	2.6	60
1906	0.4	70	58	0.8	1.1	78	53	77	0.4	67
1907	0.3	61	33	0.6	2.1	66	78	65	0.0	57
1908	0.1	55	56	1.0	2.7	76	71	60	1.0	65
1909	0.4	55	44	0.5	1.4	69	76	71	0.2	61
1910	0.5	65	64	0.7	0.8	67	62	69	0.8	58
1911	0.2	55	67	1.0	1.0	80	46	64	0.2	69
1912	0.7	62	68	0.3	0.5	79	48	71	1.4	68
1913	0.4	55	36	0.5	1.6	65	55	62	0.6	57
1914	0.7	62	60	0.5	1.4	81	57	73	0.9	71
1915	0.1	60	28	2.3	3.5	65	68	64	0.3	57
1916	0.0	52	52	0.1	1.5	75	60	52	0.4	66
1917	0.4	54	51	0.4	1.8	66	74	70	0.1	55
1918	0.6	62	59	1.1	2.1	75	67	54	1.2	65
1919	0.3	54	58	0.1	0.2	69	74	68	0.6	59
1920	1.4	61	74	0.1	0.7	78	54	56	1.9	66
1921	1.2	66	70	0.6	1.0	87	56	66	1.1	76
1922	1.4	64	38	0.8	1.7	75	48	69	0.5	66
1923	0.4	53	61	0.3	0.1	73	70	75	1.2	62
1925	0.4	57	86	0.3	0.1	77	52	62	0.1	64
Mean	0.6	60	57	0.6	1.4	74	62	66	0.8	64
σ	0.43	6.21	13.70	0.47	0.93	5.92	9.48	6.32	0.61	5.35
rx	+.58	+.58	+.50	−.49	−.49	+.44	−.44	+.40	+.38	+.37

Year	*K*	*L*	*M*	*N*	*O*	*P*	*Q*	*R*	*S*	*T*
1901	99	55	0.0	1.3	61	63	1.4	1.3	0.5	86
1902	81	37	0.7	2.4	64	79	1.7	0.9	0.8	73
1903	82	78	2.9	0.2	75	62	0.5	1.1	0.0	72
1904	81	51	0.9	1.0	55	80	0.6	-0.7	0.3	77
1905	88	66	1.5	0.0	52	62	0.6	1.1	1.8	79
1906	80	51	0.5	0.4	63	61	0.7	1.7	1.9	70
1907	84	72	0.9	1.0	68	72	2.4	1.2	1.2	75
1908	84	84	2.0	1.1	68	65	1.6	2.0	0.0	73
1909	85	78	1.2	0.0	58	64	2.3	1.0	0.4	74
1910	87	70	0.6	1.7	58	74	0.9	0.0	0.7	74
1911	83	70	1.2	1.4	57	78	0.2	0.4	0.8	70
1912	76	51	1.0	0.6	59	69	0.5	0.2	0.7	67
1913	87	60	0.3	1.0	72	72	0.7	1.0	1.0	76
1914	87	69	0.5	0.0	57	59	1.6	0.6	1.5	75
1915	80	78	2.0	2.5	76	87	0.8	1.6	0.2	71
1916	93	76	1.1	1.3	68	67	0.9	1.3	0.0	81
1917	86	49	1.8	0.4	59	59	3.4	0.6	0.5	74
1918	87	69	2.7	0.0	64	53	2.3	0.6	0.2	76
1919	86	52	2.0	0.7	59	64	2.0	0.9	3.0	75
1920	84	80	0.7	0.7	52	57	0.6	0.3	0.1	74
1921	89	64	1.6	0.4	61	61	0.3	0.5	2.4	78
1922	83	52	0.5	0.0	67	49	0.1	0.3	0.8	72
1923	89	40	0.9	2.0	42	77	1.2	0.8	2.0	78
1925	85	64	0.7	0.8	39	68	1.7	1.4	1.0	74
Mean	85	63	1.2	0.9	61	67	1.2	0.9	0.9	75
σ	4.57	12.88	0.73	0.73	8.78	9.00	0.82	0.49	0.80	3.86
rx	−.36	−.36	−.34	−.33	−.33	−.32	−.30	−.30	+.30	−.30

A=Average weekly precipitation for the week ending Aug. 25.
B=Average weekly p. m. relative humidity for the week ending Aug. 25.
C=Average weekly percentage of possible sunshine for the week ending May 26.
D=Average weekly precipitation for the week ending July 28.
E=Average weekly precipitation for the week ending May 26.
F=Average weekly maximum temperatures for the week ending May 26.
G=Average weekly p. m. relative humidity for the week ending June 9.
H=Average weekly p. m. relative humidity for the week ending Sept. 22.
I=Average weekly precipitation for the week ending May 12.
J=Average weekly mean temperatures for the week ending May 26.
K=Average weekly maximum temperatures for the week ending July 21.
L=Average weekly percentage of possible sunshine for the week ending Sept. 22.
M=Average weekly precipitation for the week ending June 2.
N=Average weekly precipitation for the week ending Sept. 29.
O=Average weekly p. m. relative humidity for the week ending May 26.
P=Average weekly p. m. relative humidity for the week ending Sept. 29.
Q=Average weekly precipitation for the week ending June 9.
R=Average weekly precipitation for the week ending June 23.
S=Average weekly precipitation for the week ending Sept. 22.
T=Average weekly mean temperature for the week ending July 21.

Omitting 1924, a new grouping of the variables occurs which is shown in Table 6, and the number is increased from 15 to 20. The exclusion of the abnormal year enables the weather data to fit the yield data better, as it was found in the previous calculations that the year 1924 was at variance with the remainder of the years when computing correlation coefficients. The coefficients of the new variables decrease from 0.58 to 0.30, a somewhat wider range than before, while the precipitation data occupy the same important position they did in the other grouping. Thus, it can be said that the rainfall is the dominant feature of the weather influence on corn yields, but that other influences modify it.

TABLE 7.—*Iowa*

Year	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	X''	X'	X
1901	25.5	21.9	23.4	22.3	23.4	23.8	22.6	22.9	23.1	23.7	25.0
1902	30.8	31.6	30.8	32.5	32.7	31.8	32.0	31.7	31.0	32.2	32.0
1903	28.5	29.6	27.0	27.2	26.1	26.5	26.9	26.7	25.3	27.2	28.0
1904	31.2	30.8	30.2	30.8	30.9	30.0	30.3	30.5	29.8	32.3	32.6
1905	31.6	30.5	31.5	32.2	31.8	32.0	31.6	31.9	30.6	33.7	34.8
1906	26.8	28.5	28.7	30.1	30.5	30.8	31.2	31.1	33.0	36.7	39.5
1907	27.0	27.1	26.4	26.8	27.1	26.8	27.0	26.4	26.2	30.5	29.5
1908	25.0	25.6	24.3	24.1	23.7	24.0	24.3	24.5	25.2	30.2	31.7
1909	27.8	28.2	28.1	27.4	27.4	27.6	27.6	27.3	27.3	32.9	31.5
1910	27.6	28.0	28.6	29.3	29.7	29.2	29.0	29.2	29.5	35.7	36.3
1911	25.4	27.0	27.5	26.9	27.0	26.4	26.7	27.1	28.3	35.1	31.0
1912	29.6	32.4	32.9	32.5	32.5	32.2	32.9	33.0	34.2	41.6	43.0
1913	27.8	27.6	27.4	26.8	27.5	27.2	27.1	26.5	26.2	34.3	34.0
1914	29.0	29.1	28.9	29.1	29.6	30.0	29.7	29.7	30.1	38.8	38.0
1915	21.1	22.2	20.4	21.5	21.2	20.2	21.0	20.6	21.2	30.5	30.0
1916	27.3	25.4	25.5	24.7	24.9	25.0	24.4	24.5	23.9	33.8	36.5
1917	28.1	28.5	27.9	27.1	26.7	27.3	27.2	27.1	26.7	37.2	37.0
1918	26.8	26.5	25.8	26.5	25.5	26.5	26.4	26.6	26.1	37.3	36.0
1919	28.5	28.6	29.8	28.7	28.1	28.3	28.2	28.2	28.0	39.8	41.6
1920	33.2	33.8	33.9	33.2	33.3	33.7	33.6	33.8	33.4	45.8	46.0
1921	30.8	30.0	30.2	30.8	30.4	30.7	30.2	30.5	29.3	42.3	42.0
1922	31.1	32.3	31.4	31.5	31.9	32.9	32.9	32.1	31.6	45.2	45.0
1923	28.4	27.5	29.0	27.9	28.1	27.5	27.2	27.4	26.9	41.2	40.5
1925	28.4	28.8	30.1	29.4	29.7	29.6	29.5	30.3	31.6	46.5	43.9
Mean	28.2	28.4	28.3	28.3	28.3	28.3	28.3	28.3	28.3		
σ	2.52	2.83	3.00	3.09	3.13	3.18	3.20	3.23	3.29		
rx	+.69	+.78	+.82	+.85	+.86	+.87	+.88	+.89	+.91		

A_1 = Weather indices computed from *A* and *D* (Table 6).
A_2 = Weather indices computed from A_1 and *T* (including *A, D, T*, Table 6).
A_3 = Weather indices computed from A_2 and *E* (including *A, D, T, E*, Table 6).
A_4 = Weather indices computed from A_3 and *B* (including *A, D, T, E, B*, Table 6).
A_5 = Weather indices computed from A_4 and *M* (including *A, D, T, E, B, M*, Table 6).
A_6 = Weather indices computed from A_5 and *P* (including *A, D, T, E, B, M, P*, Table 6).
A_7 = Weather indices computed from A_6 and *K* (including *A, D, T, E, B, M, P, K*, Table 6).
A_8 = Weather indices computed from A_7 and *C* (including *A, D, T, E, B, M, P, K, C*, Table 6).
X'' = Weather indices computed from X_1, X_2, and X_3.
X' = Weather indices − X'' with secular trend added.
X = Yields of corn, bushels per acre, Iowa (1924 omitted).

Table 7 shows the new bases computed. There is one more base this time than before, and a new computation for *X*. The coefficients increase from 0.69 to 0.91, which is more satisfactory, as the increase of 10 points in the correlation coefficient at this stage means 18 per cent increase in the reduction of standard deviation (4). The bases range from A_1, computed from *A* and *D*, Table 6, to A_8 and X''.

Due to the large number of bases, embracing nine variables, it was decided to compute the final equation on a somewhat different basis than before. The nine variables, *A, B, C, D, E, K, M, P*, and *T*, were combined in groups of three as follows: *A, B*, and *C*; *D, E*, and *K*; and *M, P*, and *T*, with the usual multiple correlation method used for each group. The equation for the first group was $\overline{X}_1 = 1.829A + 0.215B + 0.100C - 8.603$; that for the second, $\overline{X}_2 = -2.237D - 1.978E - 0.436K + 69.471$; and that for the third, $\overline{X}_3 = -2.359M - 0.170P - 0.408T + 73.121$. These three equations were then used to compute three new bases, X_1, X_2, and X_3, from which the final equation was derived. The final equation was $\overline{X} = 0.577X_1 + 0.480X_2 + 0.548X_3 - 17.183$. The computed yields derived from this equation were better in fit than

those for base A_8, due, no doubt, to a better correlation of the respective variables than would be obtained in the complicated method used before. The value of the coefficient thus obtained was 0.91, an improvement over that of base A_8 of 0.02.

This final computation was still incomplete, so the secular trend was added to make it comparable with the observed yields, as shown in column X', Table 7.

Figure 8 shows the computed and actual yields with secular trend added. It will be noted that there is a much closer fit of the data than when 1924 is included and that the year 1906, which was a bad fit before is now much better.

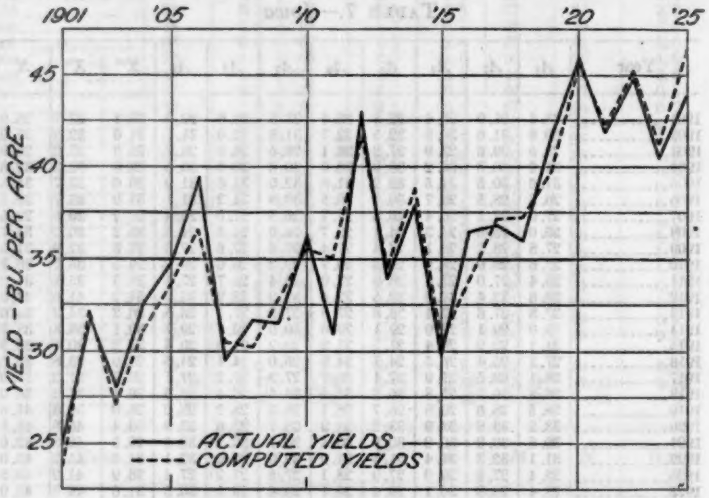

FIGURE 8.—Yields of corn, bushels per acre, for the State of Iowa. The solid line represents the actual yields and the broken line shows the computed yields. In this figure the yield data for 1924 have been omitted

No final attempt was made to forecast yields from these computations as this method of study, while it fits the data very well, is not strictly applicable for this purpose. The use of a straight-line trend in a case of this kind is limited in value. It satisfies the data under consideration, but can be of no value in forecasting, for the yields can not continue to rise indefinitely, as would be assumed from the direction of the line. Other types of curves might fit the data better, but in fitting a mathematical curve to yield data it must be remembered that extrapolation is at best very hazardous.

In computing the bases by Kincer's method, there is no effort made to reconcile the various stages of plant progression to the weather variables used and it is learned with real interest that the periods used coincide closely with the development of the corn plant in Iowa. Mr. Reed commented on this phase as follows:

I was much interested in the nine variables selected for this study. I note that they seem to have a distinct bearing on the critical planting, germination, cultivation, and pollination periods. * * * The period around May 12 is the average planting date of the bulk of the crop, and frequent rainy days, and a large total of precipitation, keeping farmers out of the fields at that time, results in a delay that is important in both yield and maturity.

The maximum temperature, the mean temperature, and the sunshine, for the week ending May 26, have a very distinct bearing on the germination. * * * The negative correlation between corn yield and rainfall in June is, I think, wholly a question of weed killing. The Iowa Experiment Station has shown that cultivation is of no value whatever except for weed killing, and that luxuriant weeds are the most serious cause of decreased yields.

It is thought that this study will serve to show the weather influences most effective in the growth of corn in Iowa. It is believed that the production of this crop will need to reach a more settled state than at present before valuable forecasting can be done from weather conditions. The farmers have developed the production of corn to procure a high yield per acre, but there is from time to time a considerable percentage spoiled by immaturity at the time of frost. Therefore it is probable that agriculture in this State will reach a settled stage when large yields per acre will be recognized as valuable, but not at the expense of full maturity, and a high-yielding corn will be developed, with a large per cent maturing before frost.

It must be admitted that, at the present stage of the development of agricultural meteorology in this country, data are usually unsatisfactory in many ways. The yield and production data are probably as satisfactory as can be obtained. The absence of organized phenological services is to be regretted as the study of crop development and its corresponding weather influences must necessarily be mere gropings in the dark until such data are available. It has been learned that a beginning in the collection of such phenological records has been made by the section director of the Weather Bureau at Des Moines, Mr. Reed, covering the whole section under his supervision, and it is earnestly hoped that nothing interferes with their continuance.

Grateful acknowledgment is made to Mr. J. B. Kincer for his kind advice and assistance in this and other papers, and to Mr. C. D. Reed for his helpful suggestions.

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RELATIONSHIP BETWEEN PRECIPITATION IN VALLEYS AND ON ADJOINING MOUNTAINS IN NORTHERN UTAH [1]

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Synopsis.—It is well known that precipitation varies widely within short distances, particularly where physical features are different. It is also well known that precipitation varies widely with elevation. Due to inaccessibility of high mountain areas few records are available to indicate the relationship of valley to mountain precipitation. In an arid region the high mountains are the source of the stream flow supplying agricultural, industrial, and municipal uses. This paper deals with variation in precipitation at different points on the valley floor and also compares the amount and distribution of precipitation on the valley floor with that above 8,000 feet.

INTRODUCTION

The development and growth of a community in an arid or semiarid region is measured by the amount and distribution of its water supply. Agriculture is dependent upon the artificial application of water for the production of crops. Communities are dependent upon water for their growth and industrial development. Hydroelectric power generation is also dependent upon the flow of streams.

The major source of waters flowing in the streams in an arid region is in the high mountains adjacent to the valleys. For many years precipitation records have been kept at valley stations. Due to the inaccessibility of the high watersheds in the winter, to the scarcity of permanent inhabitants, and to the difficulty of measuring precipitation which falls as snow, few records or precipitation are available at high elevations.

There were some 91 cooperative weather bureau stations reporting precipitation in Utah at the end of 1930. Of these 91, only 7 were at 7,000 feet elevation or above. Of the 84 below 7,000 feet elevation, 37 were below 5,000 feet elevation and 72 were below 6,000 feet elevation. In addition to the above regular cooperative stations there were 10 or 15 high elevation stations reporting only summer precipitation. Snow stakes and snow surveys furnished some data on precipitation above 8,000 feet elevation.

It has been estimated that approximately 80 per cent of the run-off of streams in Utah comes from areas above 7,000 feet elevation. This area comprises only about 20 per cent of the area of the State. It is the least known area, and yet it holds the key to the State's most valuable resource.

There is a general lack of reliable data on precipitation and other meteorological data on high watersheds in spite of the fact that these areas are the source of water supply for irrigation, domestic, and power purposes. More complete data on mountain watersheds would permit of a more complete utilization of the water resources. Such data on the high and uninhabited watersheds can be obtained only by snow surveys at the end of the precipitation season.

PRECIPITATION

Cause of precipitation.—All waters which occur above the ocean level result from, and are renewed by, precipitation in some form. Therefore, of necessity, water supplies must vary in amount as the precipitation varies. It is true that there are many modifying factors which influence the yield from a given precipitation, but precipitation is by far the most important single factor.

Condensation of moisture out of the atmosphere may occur as fog, clouds, frost, dew, rain, snow, sleet, or hail. Of these, rain or snow are by far the most important, and the term "precipitation" ordinarily means rain or snow.

Precipitation is caused by what is known as "dynamic cooling," i. e., cooling resulting from the consumption of heat in the work of expansion of rising vapor.[3]

There are three types of precipitation: (1) Convective, (2) orographic, and (3) cyclonic. Convective precipitation is caused by the expanding air in rising vertical air currents which results in dynamic cooling and condensation. Orographic precipitation is brought about by warm air striking a mountain side and being forced to rise. As the air rises it expands, resulting in dynamic cooling and precipitation. Cyclonic precipitation results from the movement of centers of high and low air pressures. The unequal heating of the earth's surface causes the formation of these pressure centers. Warm air is rising in a low pressure area, resulting in precipitation, while cold air falling in a high pressure area results in cooler weather. These pressure centers follow each other across the country from West to East and determine largely the weather during the winter months. The storms usually enter the United States on the coast of Northern California, Oregon, or Washington, and move eastward, bending southward until the continental divide is crossed, and then bending northward again and going out through the St. Lawrence River Valley.

The distance these cyclonic storms paths are deflected southward largely determines the weather and amount of precipitation that falls in Utah during the winter months. The summer precipitation in Utah results principally from local storms. The warm air on hot summer afternoons upon striking the high mountains is forced to rise. As the air rises it expands and cools rapidly causing condensation and precipitation. This type of storm explains the spotted character of the intense summer storms, so common in Utah.

Distribution of precipitation.—The climate of Utah is divided into a distinct wet and a distinct dry season. Precipitation is light during June, July, and August and heavier during the remaining months of the year. Approximately 56 per cent of the annual precipitation at Logan occurs during the period October to March, inclusive. Cyclonic storms are the source of most of the precipitation from October to June, inclusive, while local storms furnish the precipitation from July to September, inclusive. The July–September, inclusive, precipitation is approximately 16 per cent of the annual precipitation.

In general, precipitation increases with altitude. There are a few instances, however, where it has been definitely proved that after a certain elevation has been reached precipitation decreases with increased elevation.[4]

Precipitation.—There are few precipitation records in Utah available above 7,000 feet elevation. There are some records of summer precipitation at high elevations but no records of winter precipitation.

[1] Contribution from department of irrigation and drainage engineering, Utah Agricultural Experiment Station.

[2] Associate irrigation engineer (also associate member, American Society Civil Engineers). Publication authorized by director, Feb. 6, 1931.

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In Cache Valley since 1923, 18 precipitation stations have been maintained below 5,000 feet, five precipitation stations above 8,000 feet elevation, and one at 6,250 feet elevation. At the high stations, summer precipitation was measured in standard rain gages, but winter precipitation was obtained by measuring the total accumulated snow cover at the end of the winter precipitation season. These records are brought together in this paper to point out the differences in valley and mountain precipitation during summer and winter.

PHYSICAL FEATURES OF CACHE VALLEY

Cache Valley lies in the northern part of Utah. In shape it is an irregular oval, with its long axis north and south. The maximum width, about 19.5 miles, is attained at the Utah-Idaho boundary. From this point the valley narrows at both the north and the south. About two-thirds of the valley lies in Utah and the remaining one-third in Idaho. The valley area in Utah contains approximately 450 square miles.

Cache Valley is a subsidiary valley formerly occupied by Lake Bonneville. The valley is surrounded on all sides by high, rugged, deeply furrowed mountains which are spurs of the Wasatch Range. The mountains on the east side are higher and cover a greater area than do those on the west. Mount Naomi on the east side reaches an elevation of 9,980 feet while Wellsville Peak on the west reaches an elevation of 9,450 feet. The mountains on the east side of the valley comprise the catchment basin for the streams which enter from that side. The drainage area on the east side is approximately 935 square miles, while that on the west side is only 122 square miles.

Except for Wellsville and Clarkston Peaks, a small low range of mountains on the west side separates Cache Valley from Great Salt Lake Valley. The average elevation of Cache Valley is approximately 4,400 feet, and the average elevation of the watersheds contributing to the valley is approximately 7,000 feet.

The floor of the valley is a broad, slightly undulating plain, gradually sloping up to the foothills of the near-by mountains. The foothills and lower mountain slopes are marked by numerous old lake terraces and deltas, varying in width from a few rods to more than a mile. The generally uniform valley topography is broken by Newton and Smithfield Buttes and by the large irregular fan-shaped terraces extending out from the mouths of the large canyons.

The mountains on the east side of the valley are extremely rugged, with their major axis in a north-south direction. On the west side the axis of the range is also in a north-south direction, and, except for Wellsville and Clarkston Peaks the range is low and rolling. The valley is open from the north. A low range obstructs the valley from the west.

VALLEY PRECIPITATION

In general, summer storms approach the valley from the south or southwest, while winter storms approach from the north or northwest.

Figure 1 is a map of Cache Valley south of the Utah-Idaho line, including the contributary drainage area. The hatched line shows the approximate location of the foot of the mountain slopes. Within this designated line is the valley proper. The valley precipitation stations are marked by open circles and the mountain stations by solid circles.

Precipitation on the valley floor varies widely, the heavier precipitation occurring along the foothills. Isohyetal lines, indicated on Figure 1, show the general distribution of the precipitation over the valley floor. The mean annual precipitation on the valley floor varies from 11 to 21 inches. The isohyetal lines show the least annual precipitation to be over the lowest portion of the valley floor and the greatest near the foothills. The precipitation seems to increase quite uniformly with the elevation from the valley floor to the foothills. From the foothills to the top of the mountains, the precipitation increases, but the rate of increase varies widely from year to year.

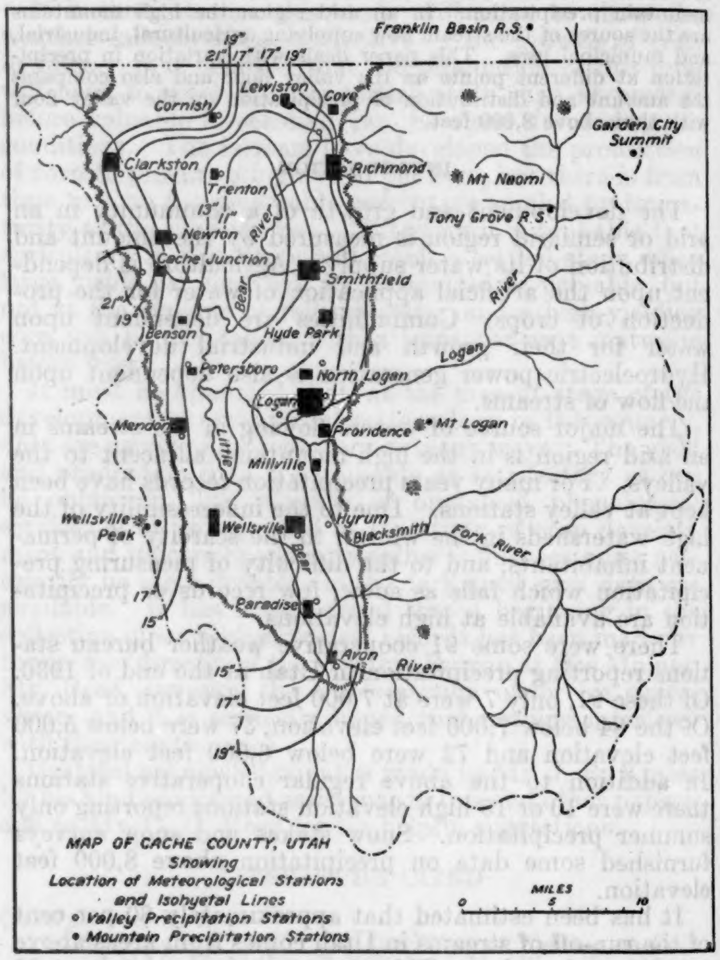


FIGURE 1

TABLE 1.—*Showing mean monthly, mean seasonal, and mean annual precipitation in Cache County, Utah*

Meteorological station	January	February	March	April	May	June	July	August	September	October	November	December	April to June, inclusive	July to September, inclusive	October to March, inclusive	Mean annual
Greenville	1.44	1.34	2.00	2.62	1.43	0.94	0.44	0.63	1.06	1.34	1.17	1.91	4.99	2.13	9.20	16.32
Avon	1.56	1.86	2.70	2.09	1.44	1.43	.75	.73	1.40	1.52	2.00	1.96	4.96	2.88	11.60	19.44
Paradise	1.20	1.96	1.27	2.15	2.00	.23	1.75	.73	1.66	1.79	1.54	1.80	4.38	4.14	9.56	18.08
Hyrum U. P. & L	.93	1.75	1.91	2.50	1.93	.86	.56	.73	1.57	1.69	1.85	2.54	5.29	2.86	10.67	18.82
Hyrum, A. Fallows	.53	1.55	1.95	1.61	1.43	.79	1.26	.81	1.20	1.34	1.42	1.81	3.83	3.27	8.60	15.70
Logan sugar factory	1.90	1.46	2.35	2.17	1.46	1.03	.37	.39	1.36	1.80	1.59	1.08	4.66	2.12	10.18	16.96
Logan, U. S. A. C	1.16	1.29	1.70	1.75	1.50	1.11	.59	.56	1.60	1.23	1.32	1.36	4.36	2.75	8.06	15.17
Petersboro	.94	1.33	1.83	1.70	1.45	.85	.56	.47	1.22	1.23	1.23	1.17	4.00	2.25	7.73	13.98
Smithfield (near)	1.10	1.68	1.83	1.92	1.83	1.07	.87	.59	1.57	1.76	1.19	.74	4.82	3.03	8.30	16.15
Cache Junction	1.30	2.12	1.95	.98	2.41	.71	1.71	1.21	1.26	1.92	1.81	2.04	4.10	4.18	11.14	19.42
Newton	.92	1.43	1.60	1.46	2.07	.97	.73	.63	1.23	1.58	1.53	1.30	4.50	2.59	8.36	15.45
Trenton	.90	.40	1.45	.50	.81	1.25	.51	.66	1.23	1.64	.45		2.56	2.40	4.84	9.80
Clarkston	.80	.50	1.56	1.88	2.14	1.17	1.15	.71	1.54	1.87	1.98	1.10	5.19	3.40	7.81	16.40
Cornish	.75	.84	2.61	.99	1.17	1.20	1.56	1.33	.91	1.78	.90	2.12	3.36	3.80	9.00	16.16
Lewiston, 1	.96	1.09	2.03	1.21	1.60	1.49	1.05	.55	1.24	1.57	1.76	1.36	4.30	2.84	8.77	15.91
Lewiston, 2	1.37	1.36	2.00	2.02	1.78	1.53	.86	.69	1.65	1.54	2.02	1.15	5.33	3.20	9.44	17.97
Richmond, 1	.77	2.15	1.67	1.97	1.72	.96	.94	.84	1.64	1.17	1.99	1.78	4.65	3.42	9.53	17.60
Richmond, 2	1.28	1.21	2.30	1.99	1.54	1.01	.77	.73	1.54	1.55	1.63	1.73	4.54	3.04	9.70	17.28

Table 1 gives the mean monthly, mean seasonal, and mean annual precipitation at each of the 18 valley stations. It will be noted that the maximum annual precipitation occurred at Avon, a foothill station, and the minimum at Trenton, a station in the bottom of the valley. Every month shows a variation between stations, but the widest variations seems to occur during June, July, and August.

The average annual precipitation for 18 stations is approximately 8.5 per cent greater than that recorded at the United States Weather Bureau station at Logan. The average valley precipitation at the 18 stations from April to June, inclusive, equals 4.43 inches, or 27 per cent of the average annual precipitation. The average precipitation July to September, inclusive, equals 3.02 inches, or 18.3 per cent. This relatively high spring and summer precipitation accounts largely for the successful dry farms on the foothills surrounding Cache Valley.

MOUNTAIN PRECIPITATION

Summer precipitation.—Cyclonic storms are the source of most of the precipitation in Cache Valley; these storms occur with the greatest frequency during the winter and early spring. The local storms furnish most of the summer precipitation. These storms occur irregularly and are extremely spotted in intensity and total amount. They apparently contribute little to the stream flow but are important in the production of range vegetation and dry-farm crops.

In 1924 several rain gages were installed on the Logan watershed at points above 8,000 feet elevation to determine the amount of summer precipitation. These gages were set up as soon as the temperatures would permit in the spring and were taken down in the fall when the snow started to accumulate on the ground. A comparison of the record at these mountain stations with the corresponding record at the United States Weather Bureau station at Logan reveals some interesting relationships. The record at the mountain stations is compared with the record for the corresponding days at the valley station. Table 2 shows the stations compared, the elevation of each station, the period of record, and the precipitation at each station in inches. Only two stations were in operation in 1924. Franklin Basin station was not started until September 1, 1924, and, therefore, is not strictly comparable. The precipitation at 9,000 feet elevation for that year (1924) was only 9 per cent greater than the valley precipitation during the period from June 27 to September 18, inclusive. At Franklin Basin (elevation, 8,200 feet) less than one-half as much rain fell as at the Logan station (elevation, 4,780 feet) during the period from September 1 to October 31, inclusive.

During the summer of 1925 the precipitation above 8,000 feet elevation was constantly higher than in the valley. At Franklin Basin it was over three times as much, and at Wellsville Peak (elevation, 8,300 feet) it was nearly twice as much. The average of all mountain stations shows the valley precipitation to be only 54.8 per cent of the mountain precipitation. This record shows the spotted character of the mountain precipitation.

Conditions were entirely different during the summer of 1926. The valley precipitation exceeded the mountain precipitation at Mount Logan and Wellsville Peak (upper), while it was less than the mountain precipitation at Wellsville Peak (lower) and Franklin Basin. The valley precipitation for 1926 averaged 104.3 per cent of the mountain precipitation. The record for 1926 also shows the spotted character of the mountain precipitation.

TABLE 2.—*Comparison of precipitation on high watershed with that of valley, U. S. A. C., Logan*

No.	Elevation	Station	Year 1924 period	Precipitation	Valley precipitation (U. S. A. C., Logan)	Year 1925 period	Precipitation	Valley precipitation (Logan)
1	6,250	Tony Grove R.S.				7/19–10/16	3.10	4.03
2	9,000	Mount Logan	6/27–9/18	1.33	1.22	7/16–10/21	6.25	4.03
3	8,200	Franklin Basin	9/1–10/31	1.22	2.76	5/15–10/3	19.85	6.40
4	9,400	Wellsville Peak				7/20– 9/25	5.35	3.50
5	8,300	do				5/25– 9/25	11.03	6.00
6	4,778	U. S. A. C., Logan	5/1 – 9/30	2.49	2.49	5/1 – 9/30	7.20	7.20
7	7,600	Summit G. C.						

No.	Elevation	Station	Year 1926 period	Precipitation	Valley precipitation (Logan)	Year 1927 period	Precipitation	Valley precipitation (Logan)
1	6,250	Tony Grove R.S.				6/1 –10/4	4.74	3.99
2	9,000	Mount Logan	5/27–10/30	3.95	5.23	6/28–10/15	5.17	3.80
3	8,200	Franklin Basin	4/10– 8/1	5.00	4.15			
4	9,400	Wellsville Peak	6/1 –10/16	4.13	5.12	6/21–10/11	2.72	3.80
5	8,300	do	6/1 –10/16	6.53	5.12	6/21–10/11	3.94	3.80
6	4,778	U. S. A. C., Logan	5/1 – 9/30	7.03	7.03	5/1 – 9/30	6.45	6.45
7	7,600	Summit G. C.				7/2 –10/4	5.15	3.61

TABLE 2.—*Comparison of precipitation on high watershed with that of valley, U. S. A. C., Logan*—Continued

No.	Elevation	Station	Year 1928 period	Precipitation	Valley precipitation (Logan)	Year 1929 period	Precipitation	Valley precipitation (Logan)
1	6,250	Tony Grove R.S.				7/10- 9/24	3.05	3.35
2	9,000	Mount Logan	6/1 -10/29	2.33	3.00	6/1 -10/18	5.40	5.93
3	8,200	Franklin Basin				7/10- 9/24	2.67	3.35
4	9,400	Wellsville Peak	6/1 - 9/15	.80	1.88	6/27-10/12	4.60	4.47
5	8,300	do	6/1 - 9/15	2.40	1.88	6/27-10/12	4.00	4.47
6	4,778	U. S. A. C., Logan	5/1 - 9/30	3.35	3.35	5/1 - 9/30	5.22	5.22
7	7,600	Summit G. C				6/13- 9/24	3.95	4.76

No.	Elevation	Station	Year 1930 period	Precipitation	Valley precipitation (Logan)
1	6,250	Tony Grove R.S.	6/7 -10/7	6.48	5.89
2	9,000	Mount Logan	6/22- 9/27	5.55	4.90
3	8,200	Franklin Basin	6/15-10/7	5.79	5.89
4	9,400	Wellsville Peak	6/7 - 9/28	8.50	5.30
5	8,300	do	6/7 - 9/28	7.73	5.30
6	4,778	U. S. A. C., Logan	5/1 - 9/30	8.45	8.45
7	7,600	Summit G. C	6/7 - 9/9	4.58	3.82

NOTE.—An oil film was used in the mountain gages to prevent evaporation. The gage was emptied near the first of each month.

In 1927 the mountain precipitation was spotted and the valley precipitation was only 95 per cent of the average mountain precipitation. The mountain precipitation was spotted in 1928, but during this season the valley precipitation exceeded the average of the mountain stations.

Precipitation on the high areas during the summer of 1929 was extremely spotted. At every station except Wellsville Peak (upper) the valley precipitation exceeded that on the mountains. The valley precipitation for 1929 was 113 per cent of the average on the mountains.

The season of 1930, which was marked by several torrential storms during the months of July and August, shows a more uniform distribution of precipitation and a heavier total than any of the previous years of record, except for 1925. The mountain precipitation for the summer of 1930 was considerably heavier than the valley precipitation, the latter being only 81 per cent of the average mountain precipitation.

Although only records for seven years are available, it is quite evident that (1) there is no fixed relationship between the valley and the mountain precipitation and (2) that the mountain precipitation is extremely spotted in character. These records show that the mountain precipitation during the summer season does not greatly exceed the valley precipitation; in fact, during some years the precipitation in the valley exceeds that on the mountains. Valley precipitation stations in this regard are not good indicators of precipitation on high-mountain watersheds during the summer. Due to the spotted character of summer precipitation on mountain watersheds, a large number of precipitation stations are necessary to obtain an average record of precipitation for any given area.

Winter precipitation.—Precipitation and temperature records at Logan and observations made on the Logan River watershed show that at elevations above 8,000 feet most of the precipitation occurs as snow after November 1, and that it accumulates from that date until after the following April 1, when the melting season usually starts. Based on the assumption that any precipitation which occurs on the watershed above 8,000 feet elevation after November 1 accumulates on the ground, a measurement of the water content of the snow cover at the end of the precipitation season and before melting begins should give approximately the total precipitation occurring between these dates.

On the Logan River watershed snow surveys have been made for seven years on three courses. These courses are all above 8,000 feet elevation and are about 15 miles apart. They have proved to be representative of the snow cover conditions above 8,000 feet over the entire area.

To make a comparison between the winter precipitation on high watersheds and valley precipitation, the valley precipitation at Logan was computed for the period, November 1 to the date of the annual snow survey. The total precipitation for this period was then compared with the water content of the snow cover on the date of the survey.

Table 3 gives the precipitation at Logan (elevation 4,780 feet) and the average water equivalent of the snow cover for the three courses above 8,000 feet elevation. The snow cover measurements represent the mean of 106 annual observations taken 100 feet apart at fixed points so that the snow cover was measured in exactly the same way each year. A comparison of precipitation, caught in a standard rain gage with accumulated snow cover, is subject to some errors due to evaporation of snow and also due to snow on the ground prior to November 1 or to melting of snow after November 1. Field observations at the beginning of the accumulation season and of the soil under the snow at the time of the snow survey apparently indicates the error from these two to be slight.

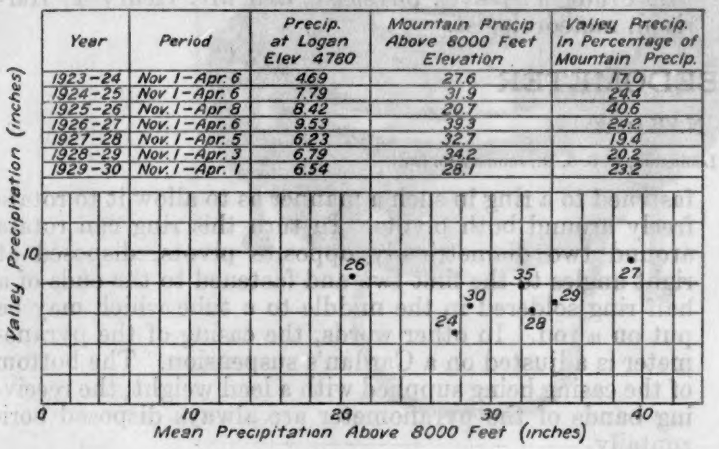
TABLE 3.—*Comparison of winter precipitation above 8,000 feet and below 5,000 feet, Logan River watershed*

Year	Period	Precipitation at Logan (inches), elevation, 4,780	Water equivalent in inches of snow cover accumulated during period given				Mountain precipitation in percentage of valley precipitation
			Franklin Basin, elevation, 8,200	Tony Grove Lake, elevation, 8,300	Mount Logan, elevation, 9,000	Mean	
1923–24	Nov. 1–Apr. 6	4.69	25.1	31.8	25.8	27.6	590
1924–25	do	7.79	28.3	35.5	32.1	31.96	410
1925–26	Nov. 1–Apr. 8	8.42	18.4	21.9	22.0	20.76	226
1926–27	Nov. 1–Apr. 6	9.53	33.8	43.5	40.8	39.30	413
1927–28	Nov. 1–Apr. 5	6.23	31.7	34.9	31.6	32.70	524
1928–29	Nov. 1–Apr. 3	6.79	31.1	36.5	35.0	34.20	503
1929–30	Nov. 1–Mar. 30	6.54	26.8	31.5	25.9	28.06	507
7-year mean		7.14	27.88	33.65	30.45	30.65	430

The few records available show that evaporation from snow cover between November 1 and April 1 is slight. The record for the period from 1923–24 to 1929–30, inclusive, shows that the average precipitation above 8,000 feet was 4.3 times the precipitation for the same period at the United States Weather Bureau station at Logan. The winter precipitation above 8,000 feet varied from 2.3 times the valley precipitation during the extremely low-water year in 1926 to 5.9 times during 1923–24.

There seems to be no relationship between the valley and mountain precipitation. The maximum valley precipitation came the same year as the maximum mountain precipitation; the second highest valley precipitation (9.53 inches against 8.42 inches) came during the same year as did the minimum mountain precipitation. Figure 2 shows the poor correlation between valley and mountain winter precipitation in northern Utah.

The minimum discharge of Logan River from 1923–24 to 1929–30, inclusive, occurred in 1926. This was year of minimum precipitation above 8,000 feet elevation; it was also a year of above-normal valley precipitation. The maximum discharge occurred in 1927, which was a year of maximum precipitation both in the valley and on the mountains. The average annual discharge of Logan River is 221,645 acre-feet, or a uniform depth over the watershed of 19 inches. This is more by 2.5 inches than the annual precipitation at Logan, a valley station. On many Utah watersheds the run-off depth is greater than the valley precipitation on these watersheds.



Year	Period	Precip. at Logan Elev 4780	Mountain Precip Above 8000 Feet Elevation	Valley Precip. in Percentage of Mountain Precip.
1923–24	Nov 1–Apr. 6	4.69	27.6	17.0
1924–25	Nov 1–Apr. 6	7.79	31.9	24.4
1925–26	Nov. 1–Apr 8	8.42	20.7	40.6
1926–27	Nov. 1–Apr. 6	9.53	39.3	24.2
1927–28	Nov. 1–Apr. 5	6.23	32.7	19.4
1928–29	Nov. 1–Apr. 3	6.79	34.2	20.2
1929–30	Nov. 1–Apr. 1	6.54	28.1	23.2

FIGURE 2

The record cited in Figure 2 shows little, if any, relationship between valley and mountain precipitation in northern Utah. This means that precipitation occurring in the valley is a poor index of the precipitation on the high watersheds or of the water-supply to be derived therefrom.

Figure 3 shows the winter valley precipitation and the winter mountain precipitation plotted against the run-off for April to September, inclusive. These curves show a poor relationship between valley precipitation and run-off. The relationship between winter mountain precipitation and run-off is much closer. Although the available record of winter precipitation on high watersheds is short, the winter precipitation as measured by annual snow surveys apparently is a good index of the water supply to be expected from such watersheds.

SUMMARY

1. Precipitation on the valley floor of Cache Valley varies widely, increasing with elevation from the bottom of the valley floor to the foothills.

2. The average spring and summer precipitation for the 18 valley stations equaled approximately 45 per cent of the total annual precipitation.

3. The summer precipitation at the valley stations is spotted, while the winter precipitation is more uniform.

4. Summer precipitation above 8,000 feet is extremely spotted.

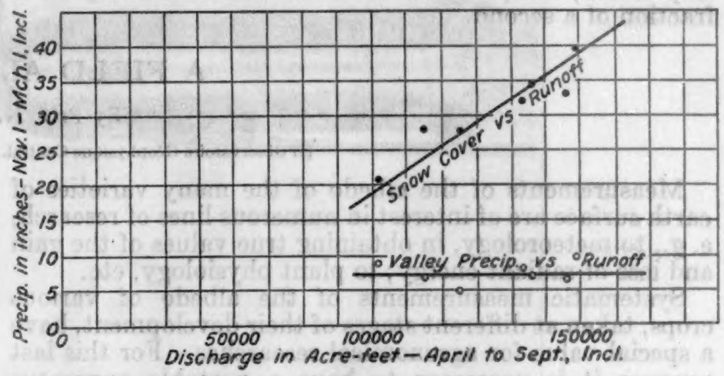


FIGURE 3

5. There seems to be no fixed relationship between the valley and mountain precipitation during the summer season.

6. Winter precipitation on high mountain watersheds is measured by snow surveys. It is quite uniform over wide areas.

7. The water equivalent of the accumulated snow cover on high watersheds is several times the valley precipitation during the period of accumulation.

8. Existing records indicate that during the winter season for northern Utah watersheds there is no relationship between valley and mountain precipitation.

9. Valley precipitation is a poor index of the probable water supplies and at times may be misleading.

10. Mountain precipitation measured above 8,000 feet elevation seems to be a good index of stream flow from that area.

THE GREEN FLASH OBSERVED OCTOBER 16, 1929, AT LITTLE AMERICA BY MEMBERS OF THE BYRD ANTARCTIC EXPEDITION

By WILLIAM C. HAINES

[Weather Bureau, Washington, D. C.]

On the evening of October 16, 1929, between 8:45 p. m. and 9:20 p. m. (180 meridian time), several members of the expedition observed a very striking example of the green flash. At the time the sun was skirting the southern horizon, its disk disappearing at intervals only to reappear again a few moments later. This fluctuation was caused by the unevenness of the barrier surface which formed the line of the horizon. The irregularities in the snow surface permitted the upper limb of the sun to appear in one or more starlike points of light from adjacent notches. These points or flares of light would sometimes have a greenish color on their appearance or disappearance. The length of time during which the green flare was visible varied from a fraction of a second to several seconds, and at times it was possible to keep it in view or to make it reappear again by raising or lowering the head. Occasionally green, orange, and red flares could be seen simultaneously at different points, giving one the impression of traffic lights. When the sun sank too low to be seen from the ground, it was still visible from elevated points such as the anemometer post or radio towers. The above effect was seen at intervals during a period lasting over half an hour.

At the time of occurrence of the phenomenon the sky was seven-tenths covered with clouds, the clear portion being along the southern horizon. A few patches of alto-stratus clouds in the vicinity of the sun showed sunset colors. There was a light southerly wind (8 miles an hour) and the temperature was −24° F. at the time. Between the sun and the camp lay a depression in the barrier within which the air was often much colder and less disturbed

than over the surounding area. Conditions seemed favorable for marked refraction, as a very shallow layer of surface air from the south underran a northerly wind all evening, which condition should have caused a marked temperature inversion.

The phenomenon was first observed by Mr. M. P. Hanson, the radio engineer, who came in and told me to go out and look at the sun, saying, "it is green." When I reached the outside it continued green. It had exactly the same appearance as an example of the green flash witnessed by the writer and others in April, 1926, between Norway and Spitzbergen, while on the Byrd Arctic Expedition, except in this case the flash lasted only for a fraction of a second.

Conditions were more favorable for its occurrence when first observed. Later the green appeared for shorter and less frequent intervals, and the orange and red flares increased in frequency.

Numerous times while on the barrier the writer looked for the green flash under quite similar conditions but failed to observe it. This fact would seem to indicate that a favorable condition of the air is necessary for its occurrence at a time when a very small part of the sun's disk is visible.

Among other members of the expedition who observed the phenomenon were Dr. Dana Coman, physician, Mr. Frank T. Davis, physicist; and Mr. Henry T. Harrison, meteorologist.

A FIELD ALBEDOMETER

By Prof. N. N. KALITIN

[L'Observatoire Géophysique Central, Leningrad, U. S. S. R., January 15, 1931]

Measurements of the albedo of the many varieties of earth surface are of interest in numerous lines of research, e. g., to meteorology, in obtaining true values of the gain and loss of radiant energy; to plant physiology, etc.

Systematic measurements of the albedo of various crops, taken at different stages of their development, have a special value for agronomical researches. For this last purpose it is necessary to have a portable apparatus allowing easy, rapid, and uninterrupted measurements.

The A. Ångström pyranometer is a very convenient apparatus for measurements of the albedo, being light and compact, but its installation proves most unhandy. The apparatus has to be fixed and leveled on a solid support (a tripod), at the end of a small rod which places it above the area to be investigated. This rod is so short that the pyranometer can be adjusted only over the edge of the area examined, e. g., field of crops. The readings of the apparatus may also be influenced by the support, and the transportation and installation of the tripod prove inconvenient and take much time. In order to eliminate these drawbacks a field albedometer, requiring neither support nor leveling, has been constructed by the author.

The design of this pyranometer is based on the adaptation of a Cardan's suspension which automatically brings the apparatus to a horizontal position. The construction of the pyranometer is as follows: In Figure 1 the receiving parts consist of 6 thin copper bands, 3 of which are coated with magnesium oxide,[1] and 3 with soot. On the back of the bands is attached a battery of 18 copper-constantan thermocouples.

The pyrheliometer is protected by a thin spherical glass cover. The casing of the pyranometer is supported from its upper part on two diametrically opposite pivots and fastened to a ring in such a manner as to allow it to rotate freely around both pivots. In turn this ring can rotate around two diametrically opposite pivots, disposed at right angles to the first two and fastened to the ends of a half ring soldered in the middle to a tube which may be put on a rod. In other words, the casing of the pyranometer is adjusted on a Cardan's suspension. The bottom of the casing being supplied with a lead weight, the receiving bands of the pyranometer are always disposed horizontally.

For the measurements of the albedo it is necessary to make the second series of readings with the receiving surfaces turned downward toward the surface to be investigated. It is sufficient, for this purpose, to turn the apparatus 180° around an imaginary axis passing through the rod. The casing of the pyranometer will be reversed, with the receiving surfaces directed downward and, having slipped 5 centimeters down along two guides (seen in the photograph), will assume a steadfast position, with receiving surfaces disposed horizontally. (See fig. 2.)

It is evident in both cases that the adjustment of the pyranometer is rapid and automatic. During observations the pyranometer is attached to a bamboo rod 3 meters long and connected by means of conductors with a galvanometer; the loop of the Zeiss galvanometer seems the most suitable in this case, being well adapted to field work. Two men, one operating the albedometer and the other taking the readings, can accomplish a very extensive piece of work during a day.

Figure 3 shows field work carried on by means of the albedometer. This apparatus also proves very convenient for measuring the albedo of water surfaces, when it is especially difficult to level the receiving surfaces.

[1] The method given by A. Ångström.

OBSERVING THE WEATHER AT MOUNT EVANS, GREENLAND

By LEONARD R. SCHNEIDER

For a person who had lived all his life in Illinois, in the heart of the Corn Belt, the weather of Greenland presented many unusual features. It will be a few of these features, arranged in a time sequence, which I wish to describe in the following.

As an introductory paragraph, it may be pointed out that two things account for the unusually large number of fair-weather days at Mount Evans. Undoubtedly the height and length of the great Sukkertoppen iceblink lying nearly 100 miles south of us was sufficient to interfere with and perhaps ward off frequent winds and storms that might otherwise come from that direction. But far more effective in the matter of bringing clear skies was the fact that the region was subject to the drying down-slope winds which prevail from off the ice cap. Being inland some 80 miles removed us from much of the wind that makes good use of the Davis Strait-Baffin Bay highway. But the camp's other dominant feature was the practically unlimited visibility, which a mountain-top position gave us.

Our first impression of Greenland weather lived up to the mental impression always created by the word "Greenland." On July 11, only two days after our arrival at Mount Evans, more than an inch of snow fell.

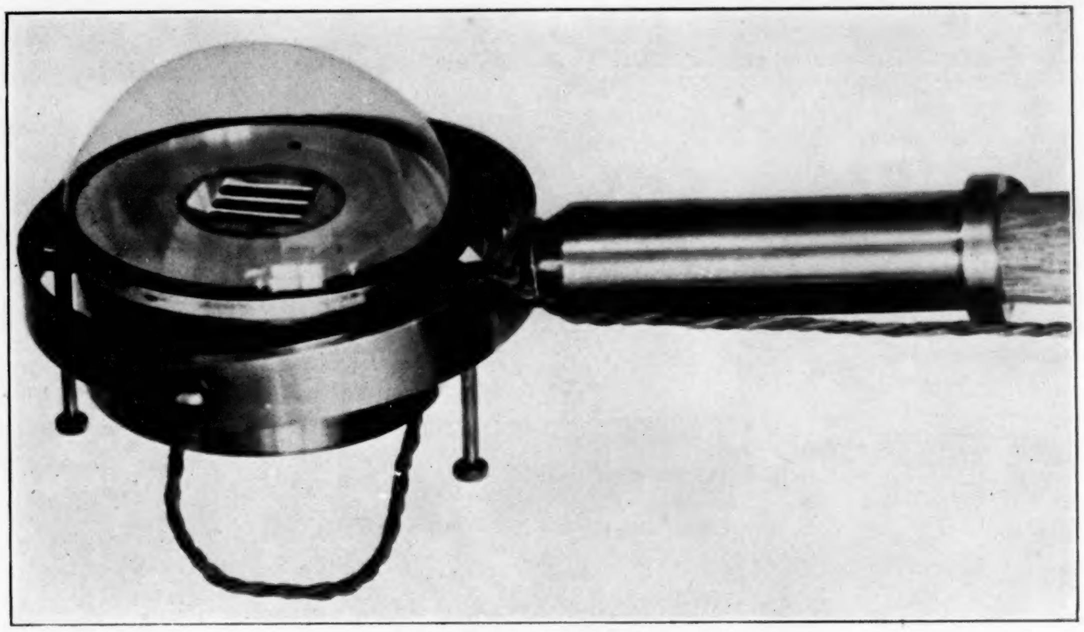


FIGURE 1.—Field albedometer, with receiving surfaces turned upward

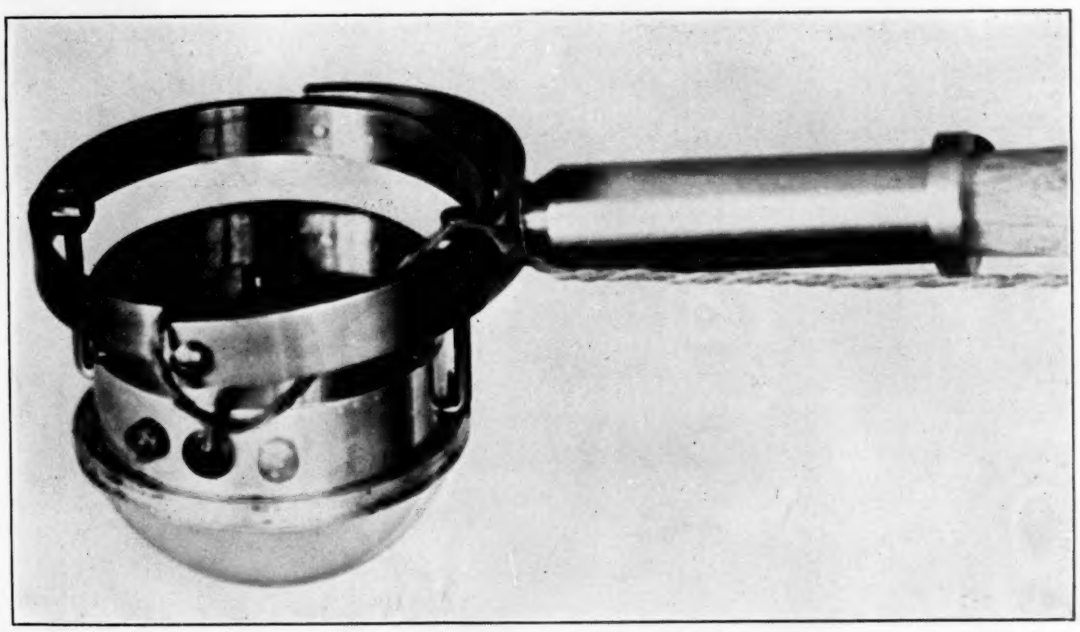


FIGURE 2.—Field albedometer, with receiving surfaces turned downward

FIGURE 3.—Observations made with the aid of the albedometer

This made the work of transferring equipment rather tedious, but the snow cover disappeared within two days and maximum temperatures in the fifties were recorded and shortly after, on July 27, the maximum for the summer, 68°, was registered. This, incidentally, was the day scheduled for the arrival of Hassell, pilot of the *Greater Rockford*. From the weather notes of that day I find these words, "perfect weather, visibility good, sky clear, wind variable and light, and highest barometer for the month."

After our disappointment caused by Hassell's first smash-up near Rockford, nature appeared to be doing all she could to lighten our spirits. At any rate, on July 23 there was a rainbow in the northwest. I believe, however, that its splendor was even surpassed by the beautiful pillar of light cast by the sun during a 10:30 p. m. sunset on July 30. The purple reflection on all the near-by lakes reached the richness of the blue of our own Crater Lake. In addition to exceedingly beautiful sunsets which some evenings seemed only to lose their beauty when the morning sun came, the next thing of note was the first appearance of the aurora borealis from 7:30 to 8:30 on the evening of August 30.

Just as we had had a fall of snow to celebrate our arrival in camp, so it was on the day of departure of Doctor Hobbs and the summer expedition, that nature provided us with a covering of white. Two days later, on the 6th of September, the three remaining Mount Evansites officially declared summer to be at an end, for a film of ice had formed on the evaporation pans. Just as a further evidence of the fact that winter was coming, I found that on September 17 at 8 a. m. my shadow measured 30 feet; on the 22d it had increased to 36 feet and on October 5 to 57 feet. These shadows kept lengthening until on December 10 the shadows and the sun disappeared from sight. It was 30 days later when we recorded the next sunrise at 11:45 a. m.

During the winter there were several unique occurrences to which I should like to call your attention. This was the winter, you remember, when the Katigat was frozen and all of northern Europe was experiencing an exceptionally cold winter, and Chicago had its greatest snowfall. In direct contrast, the west coast of Greenland had one of its mildest winters; at least records show that the January maximum was 10° higher than any January of the past 30 years. During the same month at Mount Evans, what is remarkable is that one-fourth of the days of January had hourly temperature averages above freezing.

It was during these days that we compared radiograms; those from Denmark described the ice blockade, while those from Godthavn, in Greenland, announced that the snow had disappeared and that spring flowers might be expected any time.

Unfortunately, however, these warm days were not without some discomfort, for frequently when the temperature reached the fifties the wind reached the sixties. The wind reached its maximum velocity on January 24, when the southeast wind from off the ice cap reached exactly 100 miles an hour. At this registered velocity I shall allow you to cite your own figures for what the gusts might have been. At any rate, during this blow, after some moments of anxiety, we felt relieved when the anemometer slowed up, first to the nineties, and then to the eighties and seventies, for these blasts could only tug at our house, which was securely built and streamlined against the wind. During this period of hurricane winds our well-secured radio mast was flattened against the rocks, and that gave us something to talk about, but I doubt if it equalled the remarks occasioned by the wind's wholesale disposal of our year's supply of tin cans. To have been in that barrage might have been exceedingly dangerous.

Describing the winter would not be complete without a word or two concerning the snow, and as strange as it may seem, large snowflakes were extremely rare. Most frequently the snow was as tiny pieces, fragments of flakes. It was not uncommon, however, to see ice needles. While the snowflakes were small, the frost formations were often especially well formed. Some of the frost flakes measured one-half inch in length, and on these occasions thin wires became huge ropes, and other objects changed in size accordingly.

Once I was surprised to see some whopper snowballs on the lee side of Mount Evans. Before I could photograph them, and some of them measured as much as 8 inches in diameter, the wind increased in velocity and broke these curious formations probably as quickly as they were formed. Since this was on April 2, I considered it a sort of April-fool joke.

In contrast to our Cleveland weather, I find in my notes that on April 22, the rate of melting of the snow exceeded the rate of evaporation. Only upon this occasion was there the least little mud under foot. More often, however, and at times when the down-slope winds were stronger than usual, the wind would transport for miles considerable dust that it had picked up from the the dry-land areas along the fjord.

Most of what has already been said has dealt with the winter season, and perhaps it has been so because it has been difficult to determine the date for the arrival of spring, or perhaps better, summer. Snows were frequent all during the month of April and May, and the minimum temperatures were below freezing for the most part, yet on April 23 two flies made their appearance and ducks and geese came in from the south. Finally, however, on May 15, when along the lower slopes the buttercups were showing yellow flowers almost before they had sent up their leaves, we agreed that winter must be at an end. Ice, if this be any criterion, finally disappeared from the largest of our lakes on June 3.

The following is from my notes of June 12.

> A foehn kept us busy to-day. Four balloons were sent up, one each at 9 a. m., 4 and 5 and 10:15 p. m. The last two disappeared into lenticular alto-stratus, and only the last one showed a slight backing. At 9:30 p. m., I counted 26 individual formations, but there were many others too small to count. Although during the evening the sky was practically covered with the lenticular alto-stratus, there seemed to be a level above which the formation occurred. Above that all were at more or less individual levels, with some being single and some multilayered. When the clouds came through the zenith I failed in an attempt to discover any difference in direction of movement within the cloud, that is, anything different from the general forward movement of the entire formation. When looking at the bottom of the clouds there appears to be a definite but raggy outline, and while from the side one sees a definite lens outline, some formations apparently grow down from a higher alto-stratus.

BRIEF DISCUSSION OF FOEHN CLOUDS

And now we fairly skim by an outstanding event, the midnight sun, and hurry along to the story of the schedule arrival of Parker Cramer in the Chicago Tribune plane, *Untin Bowler*. Most important in this was the fact that weather reports were coming to Mount Evans by radio three times daily from Cape Chidley, points along the west Greenland coast, Angmagssalik on the east coast, and from Iceland. The daily reports from New York were, however, much more complete, because they gave us a picture of the general weather conditions. While

Cramer was at Cape Chidley we attempted hourly communication with that station, and to the extent that fading entered in our efforts were successful in this. Cramer lost his plane at Cape Chidley, but on July 14, the day set for his arrival at Mount Evans, I find these notes, "This was the best day of the summer—clear sky, light surface winds, and moderate southwest wind aloft." A year earlier, when Hassell was expected, practically similar conditions prevailed.

In concluding this paper, I ought to relate our extreme temperatures. Winter's coldest was 41° below zero, while the maximum of the two summers was 70.1. One clear day, with a piece of black cloth, I coaxed the mercury up to 119°.

SUBSOIL MOISTURE AND CROPS FOR 1931

By HENRY C. SNYDER

[Weather Bureau Office, Denver, Colo.]

The dryness and extreme heat of 1930 were so unusual as to justify extra precautions in farming operations in 1931. In many instances wells and springs became dry that had never failed before, indicating that the subsoil water has been depleted to a dangerous point, when considering crop production for 1931. A short, dry period, such as is more or less common in the regions affected by the 1930 drought, would have more than the usual effect and cause an apparent unaccountable damage this year unless the depletion of stored moisture is considered.

It is practically certain that the drought area benefited little by hygroscopic moisture during the past winter months, and with a constant drain on capillary water for so long the outlook is very unfavorable. Water from the permanent water level may have helped some, but with our present knowledge of capillarity it seems that the subsoil could have benefited little from this source of moisture, as it is largely beyond reach. Under artificial conditions, capillarity has been known to extend 10 feet, but this required some 18 months, and the permanent water level is much deeper than this.

With regard to soil moisture, the warmth of the past winter was also detrimental, in causing more than normal evaporation. Colder weather would have been beneficial in checking evaporation and thereby holding in check the capillary water that did reach near-surface depths. The results of a cold snap in spring illustrates the point. When this occurs there is a decidedly moist layer of earth a few inches below the surface, caused by checking the capillary water and condensing the water vapor in the soil. The moist layer is usually found from 10 to 18 inches below the surface, and the moisture so stored is readily available for plant use.

Evidence of the value of a saturated subsoil was gained in an experiment in which 2 pounds of water were added to a measured amount of surface soil. It was found that after 26 hours the soil so watered had gained 3 pounds of moisture, while the soil of twice the volume immediately below had lost 1¾ pounds. This would indicate that a moist subsoil is a material aid to rainfall under normal conditions, but little or no such aid can be expected this year. Because of the dryness of the soil it is far more probable that percolation will more than offset the forces of capillarity, thus making it imperative to have adequate and timely rainfall.

During a six weeks' drought in continental Europe in 1892, fruit trees failed to mature fruit, and many trees did not recover the following year. At the same time in California the normal dry season of from four to five months did not harm the orchards, as they produced a normal crop and without the aid of irrigation; surface tillage was used to conserve moisture. The trees in Europe were shallow rooted and depended on frequent rains, while those in California were deep rooted and could stand long periods of drought. Perennials in the dry-farming sections of the United States generally draw heavily on the subsoil moisture.

The amount of water evaporated by a growing crop is so great that it is practically certain that all the moisture is not usually secured by one season's rainfall. The amount necessary to mature a crop has been variously estimated at from two hundred to eight hundred times the amount of dry matter produced. Moreover, experiments have shown that plants that have taproots use little moisture from the surface soil and these require an abundant supply from the subsoil. A crop that uses surface soil moisture for plant evaporation required heavier and more frequent rains.

CORRELATION BETWEEN WEATHER AND PUNJAB WHEAT

Volume XXV, part 4 of the memoirs of the Indian Meteorological Department (Calcutta, 1929, p. 145–161, 2 pl.), is devoted to an article on Correlation Between Weather and Crops with Special Reference to Punjab Wheat by Rao Saheb Mukund V. Unakar.

The purpose of this study is to show the results of the research being done by the Indian Meteorological Department on the problem of wheat crop prediction in the Punjab.

In this section of India, wheat is sown in October and November, while the harvesting ends by the middle of April following. The authors make several predictions during this period, one at the end of each of the months of September to March. They have worked out correlation coefficients which take into account the meteorological elements of total Punjab rainfall, Lahore maximum temperatures, and Indus River levels, and the wheat elements of area sown, gross yield, and per acre yield. The Indus River level factor is included because nearly half the area of wheat sown in the Punjab is irrigated.

Tables show correlation coefficients for the various factors involved at different months of the growing season, and charts indicate graphically the degree of accuracy attained by crop predictions based on the meteorological factors. However, no figures other than correlation coefficients were shown which would indicate the percentage error of the crop predictions. These figures, together with a reduction of the amounts of production to bushels, seem essential to a better evaluation of the work being done by the Meteorological Department. To obtain this knowledge, and also to learn the degree of accuracy shown by the official estimates, the writer has taken the figures given in Table 8 and found the following results.

Over a period of 12 years the Meteorological Department's prediction in January showed an error of 12.8 per cent from the actual yield; its error on the March prediction amounted to 11.7 per cent. That of the official estimate showed an error of 6.9 per cent, but this prediction was made at the middle of April after the

harvest. The figures just cited are obtained from averages over the whole 12-year period. The closest prediction of the Meteorological Department was within 1,000,000 bushels of the actual yield for the area studied, which totaled 126,600,000 bushels. This prediction was made in March, 1923, for the crop to be harvested in April. The closest official estimate of the Department of Agriculture was within 333,000 bushels of the actual yield, and this prediction was made in April, 1916. The greatest error made by the Meteorological Department during the 12-year period was that of their March, 1922 prediction, which was 27,500,000 bushels too low. But this error was exceeded by the official Department of Agriculture prediction made the middle of April, 1923, which was 37,400,000 bushels too high. Three of the 24 predictions made by the Meteorological Department showed a departure opposite that to the actual, while none of the 12 official Agricultural Department predictions showed such an error.

Forecasts for area sown made by the Meteorological Department and the Official Forecasting Agricultural Department for the same period of years show the following errors:

	Per cent
Average Meteorological Department error	4.5
Average Official error	5.2
Greatest Meteorological Department error	11.7
Greatest Official error	8.7
Least Meteorological Department error	.9
Least Official error	1.9

Two of the 12 predictions on area sown made by the Meteorological Department showed a departure opposite that of the actual, while none of the 12 official predictions showed such an error. The Meteorological Department predictions were made the last of October, while those of the Official Department came out the last of January.

These errors [while somewhat greater than those of some investigations of the United States Weather Bureau in Weather and Crop Studies of this Country] are small enough to indicate that the work of the Indian Meteorological Department is of significant value to Indian agriculture. Probably its greatest value comes through the fact that these predictions are made known so much earlier than the official estimates. Doubtless when other meteorological factors such as frost frequency, distribution of rainfall, cloud proportion, dust storms, and direction of prevailing wind are included by the Indian Meteorological Department in their corrections, their estimates will much more closely approach the actual.—*Earl B. Shaw*, Clark University.

E. KIDSON ON AVERAGE ANNUAL RAINFALL IN NEW ZEALAND FOR THE PERIOD 1891 TO 1925 [1]

The distribution of precipitation in New Zealand is affected by topography and the prevailing westerly winds in such manner that most rainfall occurs on the west sides of the islands. Rain shadows are noticeable in the central portions. The east shore has a higher precipitation than the central area on account of onshore winds. However, there is a tendency for the lowest rainfall to occur near the coast in the neighborhood of Cape Campbell. The highest precipitation is in the western highlands of both islands, over 200 inches, the lowest in the southeastern lowland of South Island, under 15 inches. The number of rainy days is practically nowhere excessive.

The accompanying five maps showing in detail the distribution of stations, relief, average number of rainy days, and mean annual rainfall of the Islands add greatly to the value of the work.—*Sigismond R. Diettrich.*

[1] Meteorological Branch, Department of Scientific and Industrial Research, Wellington, New Zealand, 1930, pp. 8, 5 maps.

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, 1930

Three papers of meteorological interest presented at the Bristol meeting, 1930, are noted in the report of the meeting, just published.[2]

A discussion on The Meteorological Relations of Atmospherics, by R. A. Watson Watt, E. V. Appleton, R. Bureau, and M. A. Giblett, is briefly outlined (p. 293). Mr. Watt outlined the present knowledge of the subject; Mr. Bureau described the recording of the number of atmospherics per minute. Professor Appleton compared extraterrestrial with terrestrial sources, concluding that—

The thunderstorm mechanism seems to be a more likely source than the extraterrestrial sources proposed.

Attention is called to the experimental fact found by Appleton, Watt, and Herd that, for atmospherics of local origin, negative electrostatic field changes are about 1.5 times as frequent at positive, while for those of distant origin positive radiation field changes are about 1.5 times as frequent as negative. The possible significance of this is briefly discussed.

Mr. Giblett said that observations of the sources of atmospherics made at the radio research station, Slough, Bucks, at 13.00 G.M.T. daily had been plotted and studied in connection with the current synoptic charts.

The abstracts of two papers on climatic changes follow (p. 349):

Dr. C. E. P. Brooks, Climatic Changes in Historic Times.

It appears probable that there have been during historic times certain periods when the climate of large areas differed appreciably from that of the present century. The conditions are discussed during a number of critical periods, as far as the available evidence permits:

ca. 2200 B. C. Dry in Europe and western Asia. In western and central Europe the rainfall was in places only about half the present amount.

800–400 B. C. Wet and stormy, especially in central Europe.
0–200 A. D. Approaching present conditions.
500–800 A. D. Probably rather dry, especially in central Asia.
1200–1400 A. D. Wet and stormy in northwestern Europe.
1700–1750 A. D. Dry in western Europe.

Prof. A. E. Douglass, Past Changes in Climate in Relation to Settlements in the New World.

The annual rings of trees provide a means of studying certain characters of past climates. In the southwestern parts of the United States showing an annual rainfall of 15 to 25 inches, the rings of the *Pinus ponderosa* give a very effective record of rainfall variations from year to year, increased growth accompanying increased rainfall. Long series of such ring values have been studied and variations have been found related to the 11-year sun-spot cycle.

Since, in the region referred to, the climate is fairly constant over a large area, annual characters in rings may be traced over an extended forest district and thus exact dates may be carried from tree to tree. For example, we can pass from the older central part of a living tree to the outer part of an old building beam in a village 100 miles away, and then from the central part of the latter beam to the outer part of, perhaps, a log from a distant prehistoric ruin. Thus, a chronology of rings and rainfall has been carried back to 700 A. D. But this exact dating of the rings gives also the actual years of cutting the logs provided the outermost rings are still present. Thus, in return for providing material for building a climatic history the archæologists have received the building dates of some 40 prehistoric ruins. The oldest and the largest of the ruins so far dated, is Pueblo Bonito (New Mexico) whose construction period extended from 919 to 1127 A. D. The method can be successfully applied in many parts of the world but not necessarily in all.—*C. F. B.*

[2] British Association for the Advancement of Science. Report of the Ninety-eighth Meeting (Hundredth Year), Bristol, 1930, September 3-10. London, Office of the British Association, Burlington House, London, W. 1, 1931. 472 pp.

CAUSES OF FLASHY FLOODS AND MUD FLOWS IN UTAH[3]

The report of the Utah Flood Commission, of which C. L. Forsling and Reed Bailey, and R. J. Becraft of the Utah State Agricultural College are members, was forwarded to Governor Dern on December 30.

The commission concluded that the flashy floods and mud flows in Utah, although due directly to heavy torrential rains on steep slopes, were indirectly the result of sparseness of vegetation due in some cases to natural barrenness of semibarrenness of the watersheds, but in most cases to denudation by overgrazing, fire, and overcutting of timber, named in the descending order of their importance. The floods in Davis County, the worst in the State, were almost wholly the result of man-caused denudation. The floods originated on a relatively small area at the heads of the steep canyons where there has been very heavy overgrazing on privately owned land by both cattle and sheep.

The study revealed that similar rains have occurred in the past and probably will continue to occur at intervals of a few years to several decades, but there is no evidence of a similar frequency of floods. The geological evidence shows that the floods of 1923 and 1930 mark a distinct departure from the normal geological erosion that has been going on since Lake Bonneville receded to approximately the present level of Great Salt Lake, 20,000 years or more ago. The floods of 1923 and 1930 in places cut as great a depth in the Lake Bonneville deltas as had been cut in all the years since Lake Bonneville receded. Moreover, had erosion been going on since Lake Bonneville at a rate comparable to that during the recent floods there would have been huge alluvial fans several miles in length in front of the canyons, whereas these deposits are exceedingly small. Sand, gravel, and rocks, including bowlders up to 50 tons in weight, were deposited on rich farm lands, formerly lake bottom, where the original soil was a silt. Several facts relating to erosion and deposition on the shores of Lake Bonneville, formerly overlooked by geologists, were brought to light in the study.

PHYSICS OF THE EARTH—III. METEOROLOGY

Dr. J. S. Ames in 1926, as chairman of the Division of Physical Sciences of the National Research Council, was instrumental in organizing a large committee to prepare a series of bulletins on the Physics of the Earth, the purpose being "to give the reader, presumably a scientist but not a specialist on the subject, an idea of its present status together with a forward-looking summary of its outstanding problems."

Committees were formed to prepare reports on the following subjects:

The Figure of the Earth: Gravity, Deflection of the Vertical, and Isostacy; Tides, Oceans, and Earth, Variation of Latitude.
Seismology.
Terrestrial Magnetism.
The Age of the Earth.
Field Methods for Detecting Unhomogeneities in the Earth's Crust.
Internal Constitution of the Earth.
Meteorology.
Oceanography.
Volcanology.

[3] Reprinted from Forest Service, Monthly Report of Research: December, 1930, pp 12-13.

This important project is now being realized by the appearance of the first, second, and third of the series of bulletins:

No. I treats of Volcanology.

No. II treats of the Figure of the Earth, and the present volume, No. III, the subject of this review, considers the Meteorology of the Globe. The volume consists, essentially, of a series of contributions by the members of the committee, prefaced by an introduction written by the chairman, Dr. Herbert H. Kimball, who also contributed Chapter III, Solar Radiation and its Rôle. Other committee members and their respective contributions are as follows:

Chapter I. The Atmosphere: Origin and Composition, by William J. Humphreys.
Chapter II. Meteorological Data and Meteorological Changes, by Alfred J. Henry.
Chapter III as before stated.
Chapter IV. The Meteorology of the Free Atmosphere, by Willis R. Gregg, L. T. Samuels, and W. R. Stevens.
Chapter V. Dynamic Meteorology, by Hurd C. Willitt.
Chapter VI. Physical basis of Weather Forecasting, by Richard Hanson Weightman.

The several bulletins may be purchased from the National Research Council, Constitution Avenue and Twenty-first Street, Washington, D. C.—*A. J. H.*

THE METEOROLOGY OF THE SEVENTH CRUISE OF THE "CARNEGIE[4]"

By J. H. PAUL

[Author's abstract]

An abbreviation of the usual magnetic investigations made it possible to undertake a complete meteorological program during Cruise VII of the nonmagnetic vessel *Carnegie*. In addition to the ordinary observations, a study of several special problems in atmospheric circulation over the oceans was initiated. Temperature and humidity lapse rates from quarter-deck to masthead were recorded automatically by a Hartmann and Braun electric-resistance multithermograph with three pairs of thermal elements (wet and dry) at various heights. Continuous thermograms of sea-surface temperature were obtained by a bulb-and-capillary recorder. Continuous humidity measurements were also obtained by a recording aspiration psychrometer of Negretti and Zambra manufacture for immediate use aboard and as a control on the multithermograph. These instruments were all intercompared with standard thermometers daily. A continuous record of atmospheric pressure was kept by an aneroid barograph which was daily checked by readings on standard mercurial barometers. In addition to these records, soundings of the upper air were made almost daily in the Pacific with hydrogen-inflated pilot balloons for direction and velocity of the air currents to great heights. Measurements of the rate of evaporation were carried out when conditions were favorable. Projected studies in total solar and sky radiation, although of great interest, had to be abandoned because of the difficulties encountered in working on a vessel with lofty sails and because of pressure of other work.

The great interest of meteorologists in the work of the *Carnegie* is due to the fact that she sailed in regions from which data is very scanty and was working with instruments whose accuracy is known, something one can not claim for the commercial vessels from which ocean observations are ordinarily obtained.

[4] Reprinted from Jour. Wash. Acad. Sciences, 21:46, Feb. 4, 1931.

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C. FITZHUGH TALMAN, in charge of Library

RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

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Über Temperaturen in Washington und kurzperiodische Veränderungen in der Intensität der Sonnenstrahlung. p. 735–746. figs. 24½ cm. (Strahlentherapie. 39. Bd. (1931).)

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Effect of Indian mountain ranges on air motion. Calcutta. [1930.] p. 699–745. figs. 25 cm. (Repr.: Indian journ. physics. v. 5, pt. 7.)

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Davis, Raymond, & Gibson, K. S.
Filters for the reproduction of sunlight and daylight and the determination of color temperature. Washington. 1931. 165 p. figs. 23½ cm. (Misc. pub. Bur. stand. no. 114. Jan. 21, 1931.)

Faber, O. M.
Physikalische Staubbestimmungen. Halle. 1930. vi, 60 p. figs. 21 cm. (Messen und Prüfen. H. 2.)

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SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS OBTAINED DURING MARCH, 1931

By HERBERT H. KIMBALL

For a description of instruments employed and their exposures, the reader is referred to page 41 of this volume of the REVIEW.

Table 1 shows that solar radiation intensities averaged slightly above the normal intensity for March at Madison, Wis., and Lincoln, Nebr., and close to normal at Washington, D. C. But few observations were obtained at the latter station on account of unusually cloudly conditions during the month.

Table 2 shows a deficiency in the total solar radiation received on a horizontal surface directly from the sun and diffusely from the sky at all stations for which normal values have been established, except at Gainesville, Fla., Twin Falls, Idaho, and Fresno, Calif., which report a considerable excess.

Skylight polarization measurements were obtained at Washington on only two days. They give a mean percentage of 56, with a maximum of 60 per cent on the 25th. At Madison, a measurement made on the 28th gave a percentage of 66. These are not far from average values for March at the respective stations.

SOLAR RADIATION MEASUREMENTS FROM TULANE UNIVERSITY, NEW ORLEANS, LA.

With this month there appears in Table 2 for the first time solar radiation data from Tulane University, New Orleans, La., latitude 29° 56′ N., longitude 90° 7′ W., altitude, 40 feet above sea level. The data are furnished by Prof. Henry Laurens, department of physiology of the university.

With reference to the exposure of the pyrheliometer, Professor Laurens writes that it is on a platform 40 feet above sea level, and a sketch which he furnishes shows buildings and trees in its vicinity somewhat higher than the platform. While it does not appear that any of these objects should cut off the direct rays of the sun except when the latter is near the horizon, they will cut off a considerable amount of sky radiation. The hourly totals are thereby reduced by a small but known amount.

The Eppley pyrheliometer was carefully standardized at this office before it was sent to Professor Laurens. The records are reduced by him, using our calibration results.

TABLE 1.—*Solar radiation intensities during March, 1931*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	8 a.m. / 75th mer. time	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon / Local mean solar time
		Air mass A. M.					Air mass P. M.				
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Mar. 4	3.00			0.88							2.62
Mar. 5	2.49		0.76	0.89	1.13						2.49
Mar. 11	8.38		0.86	0.92							2.26
Mar. 12	8.58		0.83	1.00	1.19						2.16
Mar. 13	2.49		0.92	1.03	1.28						2.74
Mar. 18	3.45		0.84	0.98	1.20						3.45
Mar. 24	3.00		0.74								3.45
Mar. 26	5.16		0.62	0.81	1.00						5.16
Means			**0.80**	**0.93**	**1.16**						
Departures			+0.00	−0.02	+0.01						

Madison, Wis.

Date	e.	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	e.
Mar. 2	2.16	0.97	1.08	1.20	1.36		1.35				2.36
Mar. 3	2.62		1.04	1.17							2.36
Mar. 4	1.96	1.04	1.03	1.16							1.88
Mar. 9	2.16						1.30				1.45
Mar. 10	1.96			1.29	1.43						1.52
Mar. 11	2.49						1.33				2.36
Mar. 25	3.99				1.30						3.81
Mar. 30	2.16		1.03	1.16	1.29	1.53	1.31				2.49
Means		**(1.00)**	**1.04**	**1.20**	**1.34**		**1.32**				
Departures		+0.02	+0.01	+0.04	+0.03		+0.03				

[1] Extrapolated.

TABLE 1.—*Solar radiation intensities during March, 1931*—Con.

[Gram-calories per minute per square centimeter of normal surface]

Lincoln, Nebr.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Mar. 9	1.96				1.40						3.00
Mar. 10	3.15						1.21	0.93	0.78	0.60	3.63
Mar. 13	4.57		0.82	1.01	1.28		1.34		1.03	0.94	5.36
Mar. 14	3.63		0.97	1.08	1.26						3.81
Mar. 15	2.62					1.64	1.43	1.29	1.10	1.00	2.16
Mar. 16	2.36		0.86	1.13	1.32						2.06
Mar. 18	3.99			1.06	1.26		1.29	1.09	0.93	0.78	4.37
Mar. 25	3.15		0.72	1.03							2.49
Means			0.84	1.06	1.30		1.32	1.10	0.96	0.83	
Departures			−0.09	−0.03	+0.03		+0.04	+0.01	+0.01	+0.01	

TABLE 2.—*Total solar radiation (direct + diffuse) received on a horizontal surface*

[Gram-calories per square centimeter]

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Pittsburgh	Gainesville	Fresno	La Jolla	Miami	New Orleans
	Average daily totals											
1931	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Feb. 26	314	282	296	184	247	369	185	352	427	339	240	
Mar. 5	323	331	310	149	198	372	168	472	402	360	259	382
Mar. 12	309	165	423	114	311	321	203	428	448	330	405	348
Mar. 19	286	242	329	276	260	435	180	453	446	356	491	264
Mar. 26	292	287	291	188	204	356	149	508	550	410	430	234
	Departures from weekly normals											
Feb. 26	+26	−5	−49	−5	+17	+75	+14	−40	+57	−7		
Mar. 5	+7	+34	−42	−43	−58	+66	−34	+80	+18	+21		
Mar. 12	−18	−150	+48	−90	+45	−6	−23	+58	+33	−8		
Mar. 19	−69	−79	−69	+55	−6	+85	−47	+56	−26	−14		
Mar. 26	−57	−76	−111	−49	−70	+3	−82	+36	+39	+6		
Accumulated departures on Apr. 1, 1931	−499	−2,898	−1,001	−798	+546		−1,179	+1,283	+497	+140		

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, Superintendent United States Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, Perkins, and Mount Wilson Observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time	Heliographic Diff. long.	Heliographic Longitude	Heliographic Latitude	Area Spot	Area Group	Total area for each day
1931	h m	°	°	°			
Mar. 1 (Yerkes Observatory)	12 42	−31.6	265.7	−7.6	24		
		−30.8	266.5	−8.8	18		
		−30.0	267.3	−8.9	17		
		−30.0	267.3	−8.5	35		
		−28.6	268.7	−9.2	34		
		−25.8	271.5	−7.4	17		
		−24.2	273.1	−6.8	17		
		−23.1	274.2	−6.8	98		260
Mar. 2 (Naval Observatory)	11 44	−65.0	219.6	−7.0		62	
		−13.5	271.1	−8.0		216	278
Mar. 3 (Yerkes Observatory)	12 48	−56.2	214.7	−10.3		106	
		−52.8	218.1	−9.2	12		
		−47.2	223.7	−9.5	44		
		−4.3	266.6	−9.2		60	
		−3.9	267.0	−9.6		60	
		+4.4	275.3	−7.6	180		462
Mar. 4 (Naval Observatory)	12 31	−36.0	221.9	−2.5		185	
		+19.0	276.9	−10.0	123		308
Mar. 5 (Naval Observatory)	11 50	−25.0	220.1	−8.0		154	
		+11.0	256.1	−32.0	3		
		+29.0	274.1	−9.0		185	342
Mar. 6 (Naval Observatory)	11 41	−12.0	220.0	−8.5		123	
		+40.0	272.0	−10.0		154	277
Mar. 7 (Naval Observatory)	11 18	+2.0	221.0	−10.0		123	
		+55.0	274.0	−10.5		123	246
Mar. 8 (Mount Wilson)	13 0	−89.0	115.9	+8.0	55		
		+15.0	219.9	−10.0		89	
		+70.0	274.9	−10.0		195	339
Mar. 9 (Naval Observatory)	11 34	−75.0	117.5	+10.0		247	
		+30.0	222.5	−10.5		93	
		+85.0	277.5	−12.0		93	433
Mar. 10 (Naval Observatory)	11 53	−80.0	99.2	+11.5		62	
		−60.0	119.2	+8.0		309	
		+42.0	221.2	−12.0		154	525

Positions and areas of sun spots—Continued

Date	Eastern standard civil time	Heliographic Diff. long.	Heliographic Longitude	Heliographic Latitude	Area Spot	Area Group	Total area for each day
1931	h m	°	°	°			
Mar. 11 (Naval Observatory)	11 34	−47.0	119.2	+8.0		463	
		+16.0	182.2	−10.0	6		
		+57.0	223.2	−11.0		62	531
Mar. 12 (Naval Observatory)	11 37	−50.0	103.0	+10.5		93	
		+33.0	186.0	+7.5		494	
		+76.0	229.0	−12.0		62	649
Mar. 13 (Naval Observatory)	11 37	−72.0	67.8	+10.5		154	
		−38.0	101.8	+10.0		93	
		−21.0	118.8	+6.5		432	679
Mar. 14 (Naval Observatory)	10 52	−60.0	67.0	+10.0	185		
		−23.0	104.0	+10.0		93	
		−8.0	119.0	+6.0		340	618
Mar. 15 (Mount Wilson)	11 20	−46.0	67.6	+8.0	237		
		−8.0	105.6	+8.0		24	
		+5.0	118.6	+6.0		403	664
Mar. 16 (Mount Wilson)	14 30	−30.0	68.7	+8.0	230		
		+7.0	105.7	+8.0		4	
		+20.0	118.7	+5.0		307	
		+67.0	165.7	−3.0	8		549
Mar. 17 (Naval Observatory)	10 57	−18.0	69.4	+9.0	216		
		+16.0	103.4	+9.0		15	
		+32.0	119.4	+5.0		247	
		+80.0	167.4	+2.0		93	571
Mar. 18 (Naval Observatory)	11 5	−4.0	70.2	+8.0	123		
		+12.0	86.2	+11.0	15		
		+23.0	97.2	+11.5	15		
		+43.0	117.2	+5.0		216	
		+75.0	149.2	−7.0	15		384
Mar. 19 (Yerkes Observatory)	15 41	−22.0	36.5	+7.7	17		
		−19.1	39.4	+7.7	16		
		−2.4	56.1	−19.3		31	
		+0.2	58.7	−20.8	20		
		+10.9	69.4	+6.0		125	
		+57.8	116.3	+4.1		116	
		+57.2	115.7	+6.2		29	
		+65.2	123.7	+1.7	36		
		+62.3	120.8	+7.6	17		
		+60.8	119.3	+10.5	33		440
Mar. 20 (Naval Observatory)	11 51	−8.0	39.4	+9.0		9	
		+10.0	57.4	−20.0		19	
		+23.0	70.4	+7.5	154		
		+80.0	127.4	+1.0		62	244
Mar. 21 (Naval Observatory)	11 1	+8.0	42.7	+9.0	6		
		+25.0	59.7	−21.0	6		
		+37.5	72.2	+7.0	123		135
Mar. 22 (Mount Wilson)	11 30	+23.0	44.2	+7.0	5		
		+39.0	60.2	−22.0	6		
		+50.0	71.2	+6.0	145		156
Mar. 23 (Naval Observatory)	11 48	+65.0	72.8	+5.0	123		123
Mar. 24 (Naval Observatory)	11 38	−75.0	279.8	−5.0	93		
		+80.0	74.8	+6.0	93		186
Mar. 25 (Naval Observatory)	11 29	−62.0	279.7	−6.5	93		93
Mar. 26 (Naval Observatory)	11 40	−48.0	280.4	−6.5	123		
		+75.0	43.4	+18.0	31		154
Mar. 27 (Naval Observatory)	12 18	−32.0	282.8	−7.0	93		93
Mar. 29 (Naval Observatory)	10 46	−9.0	280.3	−8.0	123		123
Mar. 30 (Naval Observatory)	11 37	+8.0	283.6	−8.0	62		62
Mar. 31 (Perkins Observatory)	14 30	−37.0	223.8	+15.0		93	
		+17.0	277.8	+2.0		124	
		+60.0	320.8	−11.0		155	372
Mean daily area for March							344

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR MARCH, 1931 [1]

[Data furnished through the courtesy of Prof. W. Brunner, University of Zurich Switzerland]

March, 1931	Relative numbers	March, 1931	Relative numbers	March, 1931	Relative numbers
1	Ec 34	11	38	21	26
2	31	12	38	22	25
3	a 24	13	d 43	23	17
4		14	47	24	a 16
5		15	b 46	25	8
6		16	41	26	8
7	a 28	17	Wc 51	27	8
8		18	a 49	28	14
9	d 32	19	38	29	16
10	32	20	40	30	9
				31	WEcc 27

Mean: 27 days 29.1.

[1] Dependent alone on observations at Zurich and its station at Arosa.
a = Passage of an average-sized group through the central meridian.
b = Passage of a large group through the central meridian.
c = New formation of a center of activity: E, on the eastern part of the sun's disk; W, on the western part; M, in the central zone.
d = Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

By L. T. Samuels

Free-air temperatures for March were below normal at all stations with the exception of the 4 and 5 kilometer levels at Ellendale (Table 1). The largest departures occurred at Groesbeck, the southernmost station.

Free-air relative humidities were practically all above normal and the vapor pressures mostly all below normal except at the upper levels at Ellendale, where the latter were above normal. At this station it is noted that the total precipitation for the month was the second largest amount for March since the establishment of the station in 1918.

Resultant winds at the 1,000-meter level were preponderantly northerly over the northern part of the country and westerly over the South Central and Southern States. It is noted that the resultant velocities at that level were appreciably greater over the West Gulf States than over the Northern States.

At 3,000 meters the same general relation occurred except that the velocities were higher.

An ideal condition for the formation of ice on the kites and wire occurred at Due West on the 31st. With a surface temperature of 9° C. the kites entered the cloud base at 1,200 meters, where the temperature was 2° C. Within the clouds the temperature decreased to -2° C. and the kite and wire took on considerable ice, causing four kites to fall to the ground with 4,600 meters of wire.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during March, 1931*

TEMPERATURE (°C.)

Altitude (meters) m. s. l.	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center. Ind. (225 meters)	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Surface	6.8	−3.2	6.6	−4.5	−4.1	−2.1	9.0	−4.3	1.8	−2.5
500	4.9	−3.4	5.3	−4.0	−4.4	−2.2	8.7	−2.9	−0.6	−2.7
1,000	2.9	−3.4	2.8	−3.9	−5.2	−1.7	6.6	−3.5	−3.6	−3.8
1,500	0.9	−3.9	0.2	−4.1	−5.2	−0.6	5.0	−3.8	−5.7	−4.5
2,000	−0.5	−3.5	−1.5	−3.6	−6.7	−0.3	2.8	−4.5	−7.0	−4.1
2,500	−2.9	−3.6	−3.2	−3.1	−9.1	−0.3	0.8	−4.3	−8.9	−3.7
3,000	−5.5	−3.7	−5.7	−3.4	−11.7	−0.1	−1.4	−3.9	−10.9	−3.3
4,000	−12.6	−5.5	−9.1	−1.9	−16.3	+0.7	−9.0	−5.7	−16.2	−3.6
5,000					−22.1	+0.8			−22.2	−3.4

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during March, 1931*—Continued

RELATIVE HUMIDITY (%)

Altitude (meters) m. s. l.	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center, Ind. (225 meters)	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Surface	65	+1	69	+5	79	+6	75	+4	79	+8
500	65	+3	65	+3	79	+7	64	−3	81	+11
1,000	64	+5	62	+1	74	+10	60	0	81	+17
1,500	61	+9	63	+3	66	+8	50	−1	75	+18
2,000	54	+8	62	+5	63	+7	48	+5	68	+14
2,500	53	+11	59	+6	65	+9	41	+2	63	+11
3,000	54	+14	58	+11	66	+9	35	−2	58	+6
4,000	56	+19	38	−5	71	+18	51	+13	61	+12
5,000					58	+5			63	+9

VAPOR PRESSURE (*mb.*)

Altitude (meters) m. s. l.	Broken Arrow, Okla. Mean	Departure from normal	Due West, S. C. Mean	Departure from normal	Ellendale, N. Dak. Mean	Departure from normal	Groesbeck, Tex. Mean	Departure from normal	Royal Center, Ind. Mean	Departure from normal
Surface	6.42	−1.80	6.84	−2.22	3.67	−0.27	9.05	−2.52	5.52	−0.82
500	5.66	−1.56	5.94	−1.98	3.61	−0.22	7.46	−2.48	4.71	−0.70
1,000	4.75	−1.18	4.80	−1.78	3.14	+0.12	6.09	−1.93	3.76	−0.59
1,500	3.93	−0.84	3.95	−1.43	2.80	+0.25	4.42	−1.67	2.94	−0.57
2,000	3.03	−0.67	3.38	−0.86	2.33	+0.18	3.60	−0.80	2.35	−0.61
2,500	2.51	−0.43	2.71	−0.52	1.96	+0.18	2.62	−0.78	1.83	−0.63
3,000	2.05	−0.32	2.07	−0.19	1.58	+0.14	1.89	−0.81	1.42	−0.71
4,000	1.41	−0.05	1.54	+0.20	1.11	+0.24	1.91	+0.05	1.09	−0.28
5,000					0.18	−0.38			0.70	−0.27

TABLE 2.—*Free-air data obtained by airplanes at naval air stations during March, 1931*

Altitude (meters) m. s. l.	Temperature (°C.)				Relative humidity (%)			
	Hampton Roads, Va.	Pensacola, Fla.	San Diego, Calif.	Washington, D. C.	Hampton Roads, Va.	Pensacola, Fla.	San Diego, Calif.	Washington, D. C.
Surface	5.7	10.7	16.9	4.1	60	72	60	64
500	2.7	9.3	15.5	0.7	59	67	61	68
1,000	−0.2	6.6	14.6	−2.0	57	63	46	68
2,000	−4.3	3.3	10.0	−5.6	49	55	32	58
3,000	−8.6	−0.7	4.6	−9.0	42	51	24	48
4,000		−7.2				56		

TABLE 3.—*Free-air resultant winds (meters per second) based on pilot balloon observations made near 7 a. m. (E. S. T.) during March, 1931*

Altitude (meters) m. s. l.	Broken Arrow, Okla. (233 meters)		Brownsville, Texas (12 meters)		Burlington, Vt. (132 meters)		Cheyenne, Wyo. (1,873 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°	
Surface	N 23 W	1.3	S 25 W	0.5	N 27 E	0.5	N 75 W	5.7	N 81 W	0.6	N 15 W	1.9
500	N 7 W	1.4	S 11 W	4.0	N 22 W	1.8			N 67 W	1.6	N	1.9
1,000	N 85 W	2.7	S 86 W	2.6	N	0.7			N 75 W	3.7	N 14 W	2.2
1,500	N 63 W	6.8	N 78 W	3.4	N 30 W	0.8			N 74 W	5.4	N 44 W	3.2
2,000	N 54 W	8.4	N 82 W	3.9	N	1.6	N 70 W	8.9	N 70 W	8.6	N 39 W	3.6
2,500	N 25 W	12.5	N 65 W	7.4	N 53 W	1.5	N 64 W	13.4	N 74 W	10.7	N 40 W	3.1
3,000			N 62 W	9.9	N 86 W	3.8	N 49 W	11.4	N 63 W	12.0	N 56 W	3.6
4,000			N 64 W	9.8	S 77 W	7.3	N 52 W	12.2	N 60 W	13.6	N 47 W	8.6
5,000									N 69 W	17.7		

Altitude (meters) m. s. l.	Groesbeck, Tex. (139 meters)		Havre, Mont. (762 meters)		Jacksonville, Fla. (14 meters)		Key West, Fla. (11 meters)		Los Angeles, Calif. (127 meters)		Medford, Oreg. (410 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°	
Surface	N 33 W	1.1	S 59 W	1.6	N 75 W	1.4	N 27 E	0.9	N 33 E	2.0	N 20 W	0.1
500	N 69 W	2.5			N 60 W	6.0	S 22 E	0.3	N 68 E	1.2	S 74 W	0.4
1,000	N 66 W	5.4	S 78 W	3.6	N 78 W	6.7	S 68 W	3.3	N 3 E	2.4	S 40 W	1.0
1,500	N 49 W	7.0	N 78 W	7.0	N 85 W	7.8	S 70 W	4.8	N 8 W	2.8	S 30 W	2.4
2,000	N 54 W	8.0	N 74 W	7.8	N 82 W	10.7	S 78 W	5.9	N 20 W	3.6	S 51 W	2.5
2,500	N 41 W	11.1	N 71 W	8.5	N 78 W	12.6	S 86 W	7.7	N 25 W	2.8	S 75 W	3.2
3,000	N 40 W	12.7	N 70 W	8.9	N 82 W	15.3	N 88 W	9.3	N 34 W	4.6	N 66 W	3.4
4,000					W	16.7	N 78 W	12.0	N 24 W	6.5	N 46 W	2.7
5,000					N 88 W	18.9						

TABLE 3.—*Free-air resultant winds (meters per second) based on pilot balloon observations made uear 7 a. m. (E. S. T.) during March, 1931*—Continued

Altitude (meters) m. s. l.	Memphis, Tenn. (145 meters)		Modena, Utah (1,665 meters)		New Orleans, La. (25 meters)		Omaha, Nebr. (299 meters)		Phoenix, Ariz. (356 meters)		Royal Center, Ind. (225 meters)		Salt Lake City, Utah (1,294 meters)		San Francisco, Calif. (8 meters)		Sault. Ste. Marie, Mich. (198 meters)		Seattle, Wash. (14 meters)		Spokane, Wash. (606 meters)		Washington, D. C. (10 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	S 69 W	1.0	N 79 W	2.0	N 36 W	1.3	N 21 E	1.7	S 86 E	2.4	N 39 W	1.4	S 4 E	1.7	S 47 E	0.4	N 45 E	1.4	S 19 E	1.5	S 16 E	1.6	N 28 W	2.0
500	N 82 W	1.9			N 53 W	3.4	N 17 E	2.0	N 82 E	2.3	N 15 W	2.7			N 27 W	2.5	N 51 E	4.3	S 19 W	5.9			N 18 W	5.6
1,000	N 69 W	5.5			N 71 W	4.2	N 2 W	2.5	N 19 E	1.5	N 5 E	3.1			N 14 W	4.9	N 54 E	2.7	S 33 W	6.1	S 30 W	4.3	N 38 W	7.0
1,500	N 67 W	6.9			N 77 W	4.7	N 25 W	5.5	N 20 W	1.7	N 1 W	3.7	S 11 E	2.2	N 25 W	4.2	N 41 E	3.3	S 68 W	3.7	S 62 W	4.6	N 52 W	7.2
2,000	N 78 W	7.9	N 13 E	1.3	N 70 W	6.7	N 35 W	7.1	N 46 W	2.5	N 29 W	4.8	S 65 W	1.4	N 28 W	3.8	N 67 E	3.6	S 71 W	3.2	S 86 W	4.9	N 64 W	7.0
2,500	N 71 W	9.0	N 3 W	2.8	N 69 W	9.1	N 33 W	9.0	N 36 W	4.1	N 30 W	5.6	N 69 W	3.5	N 47 W	6.0	N 4 E	3.0	N 2 W	3.1	N 81 W	6.3	N 59 W	8.0
3,000			N 20 W	4.8	N 80 W	9.9	N 45 W	10.0	N 39 W	5.6	N 44 W	6.0	N 56 W	5.5	N 56 W	5.9	N 20 W	4.1	N 4 E	5.9	N 89 W	6.2	N 64 W	9.2
4,000			N 45 W	9.1			N 34 W	12.4	N 49 W	6.2	N 61 W	8.4	N 52 W	6.0	N 43 W	5.1	N 12 E	5.7					N 78 W	13.4
5,000			N 48 W	13.1									N 19 W	11.4			N 28 W	6.4						

TABLE 4.—*Observations by means of kites, captive and limited height sounding balloons during March, 1931*

	Broken Arrow, Okla.	Due West, S. C.	Ellendale, N. Dak.	Groesbeck, Tex.	Royal Center, Ind.
Mean altitudes (meters), m. s. l., reached during month	2,608	2,517	3,184	2,222	2,864
Maximum altitude (meters), m. s. l., reached	4,498	4,493	4,998	4,264	[1] 9,445
Number of flights made	34	33	33	30	33
Number of days on which flights were made	30	31	28	30	30

In addition to the above, there were approximately 176 pilot balloon observations made daily at 60 Weather Bureau stations in the United States.

[1] Limited-height sounding balloon observation.

WEATHER IN THE UNITED STATES

THE WEATHER ELEMENTS

By M. C. BENNETT

GENERAL SUMMARY

The weather for March, as a whole, was persistently cool throughout the central and southern portions of the country from the Rocky Mountains eastward to the Atlantic, while the northern and western sections were warm for the season; however, during the last week a severe cold wave overspread the northwestern and central-western areas, and in some sections the lowest temperatures of the winter occurred during this period, with heavy snow as far south as northwestern Texas.

For the month as a whole the precipitation continued below normal in most sections east of the Great Plains and in large areas west of the Rocky Mountains. The Pacific Northwest, the Great Plains and the extreme Southeast, and the North Atlantic section had much more than the average, while a few localities received nearly twice the normal. The greatest shortage occurred from the Ohio Valley southward nearly to the Gulf and in the far Southwest, especially the lower Colorado Valley, Nevada, and southern California.

TEMPERATURE

The first decade of March was mainly warmer than normal near the Pacific coast and in the northern portion of the country, but colder than normal in the middle and southern portions from the Sierra crest to the Atlantic coast. The period from the 6th to 9th was especially cold in the middle and southern Plateau, Rocky Mountain, and Plains regions.

The fortnight from the 11th to the 24th was mostly warmer than normal in the western half of the country and from Minnesota to New England, but colder than normal in the middle and southern portions of the eastern half, especially the South Atlantic and East Gulf States.

The final week of March was marked almost everywhere by cold weather, especially from the western Plateau to the Mississippi River. The districts from the Black Hills southward to northwestern Texas and central Oklahoma averaged at least 15° colder than normal. However, most of California and the Northeast continued warmer than normal.

The month averaged warmer than normal in the Pacific States and a large part of the Plateau region, also in the northernmost third of the country. The northern portions of New England and New York and the vicinity of Lake Superior and the Red River of the North averaged mainly 4° to 6° above normal. The most marked excess of the monthly temperature was in southwestern California, where Los Angeles noted a mean of 66°, over 8° above normal, making this not only the warmest March but warmer than any recorded April or May.

From New Mexico and eastern Utah eastward to the Atlantic coast from Delaware Bay to Florida the month averaged colder than normal, and to the southward of the Potomac and Ohio Rivers and the southern parts of Missouri and Kansas the deficiency averaged 4° to 7°. In Florida it was almost the coldest March ever known.

The highest marks were generally not notable for March, but one station each in Arizona and California noted 100°. In many States, even as far south as Missouri and Virginia, no temperature exceeding 70° was recorded. In the western half the highest temperatures usually occurred about the 22d, near the Mississippi River about the 13th, but from Michigan and the middle Ohio Valley eastward between the 23d and the 28th.

The lowest readings were considerably below zero in the northernmost States and as far south as Nebraska; also in

most mountain and plateau States. In the eastern half the coldest weather came usually about the 4th or else early in the second decade. Most of the western half experienced its coldest weather about the 27th. At Havre, Mont., −4°, on March 26, was lower than any reading since November 15, last, save one day in January when the same mark was noted.

PRECIPITATION

The monthly amounts of precipitation are given in Table 1, p. 134.

During the first decade there was precipitation in moderate amounts over much of the eastern half of the country, the amounts being especially heavy in the region of the central valleys, and fairly heavy near Lake Michigan and the east Gulf and New England coasts.

The fortnight from the 10th to the 24th brought light to moderate amounts to numerous areas, especially the Pacific Northwest, the northern Plains and thence eastward as far as the western end of Lake Superior and much of Texas and the South and Middle Atlantic States.

The final week brought more precipitation to a large part of the country than any preceding week of March. Most districts received moderate to considerable amounts, save the Rio Grande Valley and areas westward to the south Pacific coast, a broad belt from Montana to Minnesota, and the upper Ohio Valley and the Carolinas.

As a whole, March brought considerably more moisture than any of the months just preceding, and the distribution was comparatively favorable. No State received twice the normal March quantity, on the average, and only in Arizona and California was less than half the normal received.

There usually was more than normal in Washington, Oregon, and Idaho, especially in the western part of the last named and near the lower Columbia River. Much of New Mexico and Texas, nearly all of the Plains, several parts of the Lake region, and most of the upper Mississippi Valley had somewhat more precipitation than normal. Southern Florida received much more rain than normal, and the rest of the east Gulf coast region a trifle more, while from Chesapeake Bay to Maine there was a moderate excess of precipitation.

There was a considerable deficiency from the central portions of Georgia, Alabama, and Mississippi northward to northern Ohio and Indiana; likewise in most of the middle and northern Rocky Mountain regions. The chief area of marked shortage embraced the middle and southern Plateau and Pacific regions, the scarcity of rain being notable in southwestern Arizona and far southern California.

A few stations in Oregon and Washington measured about 30 inches during March, but east of the Pacific States the greatest amount reported was 9.25 inches at a station in Florida. In Maryland, where the monthly precipitation averaged above normal for the first time since November, 1929, every station measured more than 3 inches, while in Kentucky and the Virginias, where once more the average was less than normal, the distribution was yet so favorable that the least amount reported was 1.54 inches.

SNOWFALL

The month's snowfall (see Table 1 and Chart VII) was more than normal over most central and north-central portions, and was usually greater than for any preceding month of the winter. From Kansas to the middle Ohio Valley the quantities were generally more than twice the normal, and in the Lake region, New England, and the western half of the Middle Atlantic States somewhat greater than normal.

The eastern half of the Middle Atlantic States had less than normal and the same was true of Tennessee. Minnesota likewise received somewhat less than normal.

In the far West there was comparatively little snowfall, and the elevated portions of central and southern California received particularly little. Parts of Idaho, however, and much of the Rocky Mountain region received moderately heavy falls, with somewhat improved outlook resulting as to the water supply of the coming season.

The most important falls of snow occurred from eastern Kansas to western New York about the 5th to the 11th, and over most of the Rocky Mountain and Plains regions and part of the Great Basin during the final week. This latter storm gave notable large amounts in the western portion of the central and southern Plains, where the snowfall was accompanied by intense winds and very low temperatures.

SUNSHINE AND RELATIVE HUMIDITY

Much cloudy weather prevailed from the eastern Great Plains eastward, except in the South. It was unusually cloudy in the upper Ohio Valley, the lower Lake and central Appalachian regions. Parkersburg, W. Va., reports the cloudiest month of record. In the Gulf States 50 per cent or more sunshine prevailed, while in the far Southwest from 70 to 80 per cent or more was received. In the central and northern Great Plains, and eastward to the Atlantic the relative humidity was generally above normal, except in Iowa and portions of adjacent States; while elsewhere it was generally below the average. The departures as a rule were not large, except in a few localities in the far West.

SEVERE LOCAL STORMS, MARCH, 1931

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annua Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Ventnor and Atlantic City, N. J.	4					Gale and high tide.	Part of pier swept away; boardwalk damaged.	Washington Post (D. C.).
Long Island, N. Y	4					do	Seaside cottages damaged; greatest havoc at East Hampton.	Washington News (D. C.).
New England coast	4				$2,000,000	Wind and storm tides.	Several towns partly inundated; cottages wrecked; merchandise soaked; roads washed out; traffic stalled. Severest damage between Boston and Salem, Mass.	Evening Star (Washington, D. C.).
North-central States (parts of).	5-9					Snow, wind, glaze.	Wires, poles, and trees damaged; highways obstructed; trains off schedule.	Official, U. S. Weather Bureau
Bossier City, La	6	8 p. m.	66-440		5,000	Tornado	5 buildings practically demolished; telephone poles blown down; path 3 miles long.	Do.
Memphis, Tenn.	7					High wind	Steamer George Woods sunk	Do.
Asbury Park to Sandy Hook, N. J.	8				75,000	Wind and high tides.	Chief damage by water, character not reported.	Do.

Severe local storms, March, 1931—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Knoxville, Tenn. (near)	8					Snow	Minor property damage	Official, U. S. Weather Bureau.
Memphis, Tenn.	8					High winds	Two boats blown from dock and sunk	Do.
Maryland (central part)	8					do	Some buildings damaged, especially in Washington County.	Do.
Northport section of Long Island, N. Y.	8				50,000	do	Summer homes and bathhouses damaged	Do.
Westchester County, N. Y.	8					do	Thousands of dollars damage to houses, trees, signs, windows, and telephone and power lines.	Do.
Massachusetts, New Hampshire and Vermont.	8-9					Snow and wind	Transportation crippled over large area	Do.
Eastern Shore, Virginia and Maryland.	16-17				$1,000,000	Heavy snow and high winds.	Damage chiefly to overhead wires	Do.
Desdemona, Tex.	19	7.45 p. m.	1,760			Wind and hail	Damage chiefly to oil derricks; gardens injured.	Do.
Clinton, Okla.	19	p. m.		2	60,000	Tornado	Store and school annex demolished; 12 homes unroofed; a score of persons injured; path 3 blocks wide.	Washington News (D. C.).
Pensacola, Fla.	21	a. m.				High wind	2 boats beached; sign boards blown down: windows broken.	Official, U. S. Weather Bureau
Colorado, Iowa, Kansas, Missouri, Nebraska, Oklahoma, Wisconsin, and Wyoming, parts of.	25-28			25		Blizzard	Highways and country roads impassable; thousands of cattle killed; great loss of sheep and hogs; trains delayed; 5 children died in school bus stalled near Towner, Colo., on the 27th; scattered deaths elsewhere.	Do.
Kerr, Kendall, and Blanco Counties, Tex.	27	12.15 a. m.-1 a. m.	[1] 15 mi.		10,000	Hail	Considerable damage to crops, gardens, and buildings; some loss of livestock.	Do.
Jacksonville, Fla.	28					Wind squall	Considerable damage to trees and hanging signs; small pleasure yacht damaged dock and boat slips.	Do.
Macedonia, Fla. (near)	28	4-5 p. m.				Wind	Small buildings unroofed; trees uprooted	Do.
Mulberry to Winter Haven, Fla.	31	9.30 a. m.-10.30 a. m.	100		50,000	Tornado	A number of residences damaged, 1 completely demolished; considerable injury to groves; several persons injured; path 20 miles long.	Do.
Indian River City, Fla.	31	11.30 p. m.			2,000	Wind	1 residence, several garages, and a water tank damaged.	Do.
Talbot, Meriweather, and Upson Counties, Ga.	31				30,000	Series of severe hailstorms.	Damage almost entirely to peach trees; 4 persons injured.	Do.
Alabama (central and southern counties).	31			1		Hailstorms and 2 tornadoes.	Considerable damage to farm buildings and other property in Coffee and Elmore Counties by tornadoes; damage by hail in Clinton County.	Do.

[1] Mi. signifies miles instead of yards.

RIVERS AND FLOODS

By MONTROSE W. HAYES

Floods in March were of minor consequence. The few rivers that overflowed were out of banks for a very short time and no high stages were reached.

During the week beginning March 22 the temperatures were in the fifties and snow melted rapidly over the upper part of the Susquehanna Basin, in New York. Rain late in the week further augmented the melting and the Chenango and Tioughnioga Rivers and smaller streams ran bankful. Some highways along the Tioughnioga were flooded, and a man was drowned, due to the overturning of a canoe by the swift current, at Blodgetts Mills, near Cortland, N. Y. There was no other flooding in the Atlantic Seaboard drainage.

The St. Francis River, in southeast Missouri and northeast Arkansas, and the Black River, in northeast Arkansas, were out of their banks in the second week of the month, but the overflow was slight and the damage was almost negligible.

The Sulphur River, a tributary of the Red, was in very moderate flood twice. The rises were rapid and there was a total loss of about $12,000 in livestock, and about an equal saving made possible by the flood warnings.

In the Trinity River, in Texas, there were slight overflows during the first half of the month. The damage was confined to levees under construction.

Some of the rivers of Washington and Oregon were in flood on March 31. These floods will be considered in the April, 1931, MONTHLY WEATHER REVIEW.

The following reports from officials in charge of Weather Bureau offices are considered of interest:

Cairo, Ill.—Ohio River dams in this district were lowered on February 14, except No. 52, which remained up till February 17. The dams had been up since the last week in May, 1930. They were originally intended as an aid to navigation in the summer and autumn low-water periods, but the prolonged drought made necessary their operation through the winter.

New Orleans, La.—The Mississippi and Atchafalaya Rivers were unusually low for the season. Lower stages have been recorded, notably in the first half of March, 1895, but the absence of any material rise in March, 1931, gave an average stage of 3.1 feet on the Carrollton (New Orleans) gage, which is lower than any previous average stage for the month.

Table of flood stages in March, 1931

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC DRAINAGE					
	Feet			*Feet*	
Chenango: Sherburne, N. Y.	8	29	29	8.1	29
MISSISSIPPI DRAINAGE					
St. Francis:					
Chaonia, Mo.	22	8	9	23.8	9
Fisk, Mo.	20	9	12	23.2	10
St. Francis, Ark.	18	13	17	19.4	15
Black: Black Rock, Ark.	14	8	12	17.5	9
Sulphur: Ringo Crossing, Tex.	20	3	5	24.0	3
		28	28	22.0	28
WEST GULF DRAINAGE					
Trinity:					
Dallas, Tex.	28	1	5	31.8	3
		8	9	28.7	8
Trinidad, Tex.	28	6	10	29.5	8-9
PACIFIC DRAINAGE					
North Santiam: Mehama, Oreg.	15	31	(1)	15.5	
Santiam: Jefferson, Oreg.	10	31	(1)	15.5	
Willamette: Harrisburg, Oreg.	10	31	(1)	10.6	

[1] Flood continued into April.

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

NORTH ATLANTIC OCEAN

By F. A. Young

The weather conditions over the North Atlantic during March were abnormal in some respects. Table 1 shows the exceptionally large negative departure at Horta, which indicates that an area of low pressure displaced the usual North Atlantic HIGH during the greater part of the month. While no reliable normal is available for Julianehaab, Greenland, an examination of the barometric readings at that station for a number of years shows that the positive departure for the current month was probably not far from 0.50 inch. Table 1 also gives an unusually large positive departure at Lerwick, Shetland Islands, which according to the Pilot Chart, is situated not far from the southern limit of the Icelandic LOW. It is not strange, therefore, that due to the reversal of the normal pressure distribution, the usual "westerlies" were replaced at times by winds of gale to hurricane force from all points of the compass, over a large section of the steamer lanes.

Judging from reports received, the number of days with gales was considerably above normal over the region between the Azores and the American coast, where they were reported on from 5 to 6 days in different 5° squares, while they were less prevalent than usual north of the forty-fifth parallel, occurring on from 4 to 5 days in any one square.

The number of days on which fog was reported in different localities is as follows: Over the Grand Banks, from 3 to 6 days; along the American coast, between the thirty-fifth and forty-fifth parallels, from 2 to 7 days; over the steamer lanes, between the tenth and forty-fifth meridians, from 2 to 4 days; along the European coast, from 3 to 9 days; in the vicinity of the Madeiras, 2 days; in the Gulf of Mexico, 1 day.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m. (seventy-fifth meridian), North Atlantic Ocean, March, 1931*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.97	(1)	30.42	11th	29.20	6th.
Belle Isle, Newfoundland	30.02	[2]+0.22	30.54	28th	29.00	1st.
Halifax, Nova Scotia	29.85	[3]−0.11	30.48	28th	28.86	5th.
Nantucket	29.84	[3]−0.18	30.32	28th	29.16	4th.
Hatteras	29.90	[3]−0.20	30.28	27th	29.22	3d.
Key West	30.00	[3]−0.08	30.24	13th	29.76	31st.
New Orleans	30.03	[3]−0.06	30.28	9th	29.64	31st.
Cape Gracias, Nicaragua	29.93	[2]−0.05	29.98	10th [4]	29.90	2d.[4]
Turks Island	30.04	[2]+0.02	30.18	13th	29.86	3d.
Bermuda	29.88	[3]−0.26	30.16	7th	29.52	4th.
Horta, Azores	29.63	[3]−0.49	30.06	22d	29.16	16th.
Lerwick, Shetland Islands	30.04	[2]+0.34	30.55	24th	29.53	13th.
Valencia, Ireland	29.79	[2]−0.11	30.36	24th	29.35	19th.
London	29.95	[2]−0.01	30.48	25th	29.62	1st.

[1] No normal available.
[2] From normals shown on Hydrographic Office Pilot Charts, based on observations at Greenwich mean noon, or 7 a. m., seventy-fifth meridian time.
[3] From normals based on 8 a. m. observations.
[4] And on other dates.

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Charts VIII to XIII cover the period from the 1st to 6th. Charts VIII and IX give the position of the LOW that appears on Charts X and XI for February 27 and 28, respectively, while Charts X to XIII show the conditions from the 3d to 6th, when exceptionally severe weather prevailed over different sections of the ocean. From the 3d to 5th the American coast was swept by the most severe storm of the month, reaching its greatest intensity and extent on the 4th, while on the same day westerly gales also occurred in the vicinity of the Azores.

From the 7th to 10th heavy weather still prevailed between the Azores and fiftieth meridian, while on the 7th Pensacola was near the center of a LOW, and on that date as well as on the 8th moderate gales were reported in the Gulf of Mexico. The barometric reading at Pensacola rose from 29.60 inches on the 7th to 30.16 inches on the 9th, and on the latter date a "norther" was over the western section of the Gulf, where vessels reported northerly winds, force 7 and 8, with barometric readings of from 30.22 to 30.38 inches. The LOW reported near Pensacola on the 7th moved northeastward and was central near Washington on the 8th; thence it continued in its northeasterly movement, accompanied by moderate to strong gales.

On the 11th and 12th gales of force 8 and 9 occurred over the middle section of the steamer lanes, and on the 12th to 14th westerly and northwesterly gales were also reported in the vicinity of the Bermudas.

On the 14th a depression was central about 300 miles northwest of the Azores that drifted slowly eastward and developed into a severe disturbance; during the period from the 15th to 17th westerly to northwesterly winds of from force 8 to 11 pervailed between the twenty-fifth and forty-fifth meridians.

On the 17th there was also a LOW off the Virginia Capes that moved northeastward, and moderate to whole gales were encountered over a limited area, between the thirty-fifth and forty-fifth parallels, during the period from the 17th to 19th.

From the 18th to 21st heavy weather was reported by a number of vessels in the steamer lanes, although on the 20th and 21st moderate weather prevailed over the greater part of the ocean.

On the 22d westerly winds of moderate gale force occurred off the west coast of Florida, and on the 23d the center of the LOW was about 200 miles east of Hatteras, while the disturbance had increased in both intensity and extent. On the 22d there was also a LOW central near 40° N., 50° W., that moved steadily eastward, the storm area covering a considerable portion of the steamer lanes from the 23d to 25th.

From the 26th to 31st moderate weather was the rule over the greater part of the ocean, although gale reports were received from vessels in widely separated localities. On the 31st a well-developed depression was over the eastern section of the Gulf of Mexico, and on the same day the land station at Tampico, Mexico, reported a northerly wind, force 9, barometer 30.04 inches.

OCEAN GALES AND STORMS, MARCH 1931

Vessel	Voyage From—	Voyage To—	Position at time of lowest barometer: Latitude	Position at time of lowest barometer: Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
NORTH ATLANTIC OCEAN			° ′	° ′				Inches					
Elkhorn, Am. S. S.	Houston	Bremen	40 00 N	50 00 W	Mar. 1	2 a, 1	Mar. 2	29.07	WNW	NNW, 8	W	W, 11	WSW-WNW.
Gatun, Hond. S. S.	New Orleans	New York	29 30 N	79 40 W	Mar. 3	2 a, 3	Mar. 4	29.31	N	NW, 10	N	N, 12	N-NW.
Standard Arrow, Am. S. S.	Beaumont	do	31 18 N	76 01 W	do	6 a, 3	Mar. 3	28.99	W	W, 12	W	—, 12	W-WNW.
Zacapa, Am. S. S.	Santa Marta	do	34 10 N	74 33 W	do	10 a, 3	Mar. 4	28.96	E	NE, 10	NW	NE, 12	NE-N-NW.
San Tirso, Br. S. S.	Minatitlan	United Kingdom.	31 45 N	63 30 W	do	6 p, 3	Mar. 8	29.38	S	SSW, 9	NW	SSW, 10	S-SW-W.
Nosa Prince, Am. S. S.	Canal Zone	Tampico	11 45 N	80 12 W	do	Mdt, 3	Mar. 5	29.81	N	N, 8	NE	—, 9	N-NE.
Knoxville City, Am. S. S.	New York	Port Said	39 54 N	45 48 W	Feb. 27	2 a, 3	Mar. 4	29.18	WNW	NW, 6	W	NW, 10	NW-W.
Quaker City, Am. S. S.	Hull	Philadelphia	41 15 N	66 40 W	Mar. 3	2 p, 4	Mar. 5	28.82	NNW	NNW, —	NW	NE, 12	
San Macedonio, Br. S. S.	Puerto Mexico.	United Kingdom.	40 45 N	57 27 W	do	7 a, 4	do	28.90	E	ESE, 3	SW	E, 11	E-S-SW.
Gonzenheim, Ger. S. S.	Hamburg	Charleston	31 56 N	73 35 W	Mar. 4	Noon, 4	do	29.36	S	W, 8	NW	—, 10	S-W.
Samland, Belg. S. S.	Halifax	London	43 00 N	60 56 W	do	2 a, 5	do	28.80	E	SSW, 9	SW	ENE, 12	ENE-S-SSW.
Persephone, Danzig M. S.	Bremerhaven	Las Piedras	44 40 N	19 30 W	Mar. 5	8 p, 5	Mar. 6	28.94	S	SW, 8	NW	—, 10	SSW-SW.
River Hudson, Br. S. S.	Oran	Boston	35 46 N	57 07 W	Mar. 6	3 a, 6	do	29.52	WSW	WSW, 8	WNW	WNW, 11	Steady.
Nosa Prince, Am. S. S.	Canal Zone	Tampico	22 21 N	89 05 W	Mar. 7	1 p, 7	Mar. 9	29.91	NNW	NNW, 7	NNW	—, 9	N-NE-NNW.
Boston City, Br. S. S.	Fowey	Boston	46 52 N	37 48 W	Mar. 6	4 a, 7	do	28.92	ESE	N, 10	N	N, 10	SW-W-N.
Marie Leonhardt, Ger. S. S.	Charleston	Bremen	48 40 N	15 25 W	Mar. 7	2 p, 7	do	29.28	E	E, 8	E	E, 10	Steady.
Momus, Am. S. S.	New York	New Orleans	35 50 N	75 10 W	Mar. 8	1 p, 8	Mar. 10	29.34	WSW		W	W, 10	WSW-W.
Berlin, Ger. S. S.	do	English Channel.	41 40 N	58 22 W	Mar. 9	2 p, 9	Mar. 9	29.40	SE	SE, 10	SSE	—, 10	ESE-SSE.
Extavia, Am. S. S.	Gibraltar	Boston	37 00 N	17 50 W	Mar. 10	2 a, 10	Mar. 10	29.38	S	S, 7		—, 10	S-WSW.
Ala, Am. S. S.	New York	Antwerp	45 10 N	44 04 W	do	Noon, 11	Mar. 11	29.28	SE	SSE, 10	WSW	—, 10	SE-S-SSW.
Duquesne, Am. S. S.	Manchester	New Orleans	38 39 N	40 53 W	Mar. 14	9 a, 15	Mar. 17	29.25	W	W, —	NW	NW, 10	W-NW.
Guadeloupe, Fr. S. S.	St. Nazaire	Canal Zone	40 25 N	19 17 W	do	8 a, 15	Mar. 18	29.10	ESE	SW, 6	NW	SW, 11	
Standard, Am. S. S.	Baton Rouge	New York	38 25 N	74 30 W	Mar. 16	Mdt, 16	Mar. 17	29.70	NW	NNW, 8	NW	—, 10	Steady.
Emanuel Nobel, Belg. S. S.	Rotterdam	do	40 38 N	68 11 W	do	Mdt, 16	Mar. 16	29.54	E	NE, —	NNE	NE, 10	E-N-NNW.
Mercier, Belg. S. S.	Antwerp	Canal Zone	36 00 N	35 20 W	do	1 a, 16	Mar. 17	29.49	W	NW, 10	NW	NW, 10	Steady.
Tulsa, Am. S. S.	Manchester	Charleston	46 00 N	24 26 W	Mar. 17	6 p, 17	Mar. 18	28.99	N	N, —	N	N, 10	Do.
Steel Age, Am. S. S.	Port Said	Mobile	30 40 N	56 53 W	do	11 p, 17	Mar. 17	29.76	S	S, 12	W	S, 12	S-W.
Extavia, Am. S. S.	Gibraltar	Boston	37 10 N	51 50 W	Mar. 19	1 a, 19	Mar. 20	29.66	WSW	WSW, 9		—, 10	WSW-W.
West Maximus, Am. S. S.	Antwerp	Mobile	25 40 N	83 30 W	Mar. 21	—, 22	Mar. 22	29.97	W	W, —	NE	W, 8	W-WNW.
Karlsruhe, Ger. S. S.	Bremerhaven	New York	43 42 N	51 25 W	Mar. 18	2 a, 22	do	29.22	N	N, 9	NW	—, 9	
West Cawthon, Am. S. S.	Trinidad	Boston	37 20 N	68 25 W	Mar. 22	2 p, 22	Mar. 23	29.25	E	E, 10	E	E, 10	E-S.
Tampa, Am. M. S.	Port Said	do	43 05 N	38 53 W	do	4 a, 23	Mar. 25	29.10	S	SSE, 5	N	WNW, 10	S-SSE-W.
Viborg, Dan. S. S.	Norfolk	London	47 50 N	30 10 W	Mar. 23	4 p, 25	do	29.67	S	SE, 10	SSE	SE, 10	SE-SSE-SE.
Persephone, Danzig M. S.	Las Piedras	Southampton	34 00 N	47 20 W	Mar. 28	4 a, 29	Mar. 30	29.45	SE	N, 10	NNE	N, 10	NE-N-NNE.
Nosa King, Am. S. S.	W. coast South America.	New Orleans	25 00 N	86 50 W	Mar. 30	—, 31	Apr. 1	29.73	E	SW, 7	NW	WNW, 10	SW-WNW.
NORTH PACIFIC OCEAN													
Emp. of Asia, Can. S. S.	Yokohama	Vancouver	45 58 N	166 22 E	Feb. 28	10 p, 1	Mar. 4	28.40	ENE	NW, 7	SW	W, 9	ENE-NW-N.
San Luis Maru, Jap. M. S.	Kudamatsu	San Pedro	40 53 N	172 20 W	Mar. 1	6 p, 2	Mar. 3	29.24	SE	SW, 7	WNW	S, 9	SSW-SW-W.
Bellingham, Am. S. S.	Tacoma	Yokohama	49 46 N	174 12 E	do	10 p, 2	do	28.42	SE	SSE, 9	SW	SW, 10	SE-S.
Pres. Pierce, Am. S. S.	Victoria	do	48 15 N	168 00 E	do	4 a, 2	Mar. 5	28.60	SE	NW, 12	NW	NW, 12	SSE-NW-W.
Pres. Jefferson, Am. S. S.	Yokohama	Victoria	49 47 N	176 20 W	Mar. 2	8 p, 2	Mar. 2	29.23	SE	SSE, 9	S	SSE, 9	SE-SSE.
Golden Sun, Am. S. S.	Otaru	San Francisco	47 03 N	155 10 W	do	10 a, 3	Mar. 4	29.77	S	S, 11	WSW	S, 11	Steady.
Pres. Grant, Am. S. S.	Yokohama	Honolulu	36 06 N	152 48 E	Mar. 4	10 a, 5	Mar. 5	29.57	WSW	SSW, 9	NNW	SSW, 9	SW-WNW.
Manoa, Am. S. S.	San Francisco	do	37 34 N	123 21 W	do	6 p, 4	do	29.86	W	W, 9	W	W, 9	Steady.
Steel Worker, Am. S. S.	Kahului	Yokohama	33 15 N	142 55 E	do	12 p, 4	do	29.58	S	SSW, —	NW	SSW, 9	SSW-WSW.
Oregon, Am. S. S.	Chefoo	Portland	46 40 N	179 30 E	do	7 p, 4	do	29.13	WSW	WSW, 10	W	WSW, 12	WSW-W.
Kiyo Maru, Jap. S. S.	Tokuyama	San Pedro	40 50 N	153 00 E	Mar. 5	8 a, 5	Mar. 6	28.98	NNE	N, 8	W	WNW, 9	4 pts.
Soyo Maru, Jap. M. S.	Portland	Yokohama	49 20 N	165 00 E	do	2 a, 5	do	28.15	SE	ESE, 6	NW	WNW, 12	ESE-WNW.
Bellingham, Am. S. S.	Tacoma	do	46 52 N	163 45 E	do	Mdt, 5	Mar. 7	28.18	E	S, 6	WNW	NW, 10	SE-S-W.
Atago Maru, Jap. M. S.	Yokohama	San Francisco	41 00 N	164 00 E	do	8 p, 5	do	29.05	SW	SW, 8	W	W, 10	SW-W.
Somedono Maru, Jap. S. S.	Muroran	Columbia River.	48 17 N	173 51 E	do	8 p, 6	do	28.22	SE	SSW, 11	WSW	SW, 11	SSW-SW.
Akagisan Maru, Jap. M. S.	Yokohama	San Francisco	42 00 N	176 02 W	Mar. 6	6 a, 6	Mar. 6	29.43	S	SW, 9	SW	SW, 9	S-SW.
Courageous, Am. M. S.	Shanghai	San Pedro	36 40 N	147 30 E	Mar. 7	3 p, 8	Mar. 8	29.23	SSE	SW, 8	NW	SW, 10	SSE-SW-S.
San Pedro Maru, Jap. M. S.	Moji	San Francisco	36 59 N	150 41 E	do	—, 7	do	29.24	S	SW, 8	NW	SSW, 9	S-SW-W.
Kiyo Maru, Jap. S. S.	Tokuyama	San Pedro	44 29 N	169 18 E	Mar. 8	4 p, 8	Mar. 9	28.52	SE	SW, 8	WSW	WSW, 9	4 pts.
Bellingham, Am. S. S.	Tacoma	Yokohama	44 32 N	158 30 E	do	8 a, 8	do	28.44	SSE	N, 10	WNW	N, 10	SSE-N.
Elmworth, Br. M. S.	Shanghai	Victoria	44 02 N	161 00 E	do	8 a, 8	do	28.47	WNW	SW, 6	W	NW, 10	SW-WNW.
Dakotan, Am. S. S.	Los Angeles	New York	13 53 N	96 26 W	do	2 p, 8	do	29.93	NE	NE, 10	N	NE, 10	NE-NNE-N.
Heian Maru, Jap. M. S.	Yokohama	Seattle	42 51 N	156 05 E	Mar. 7	4 a, 8	Mar. 10	28.74	SSW	W, 5	SSW	—, 10	WSW-W.
Chief Capilano, Br. S. S.	Karatsu	Vancouver	46 37 N	165 47 E	Mar. 10	11 a, 10	do	29.01	E	NE, 3	SW	S, 10	S-SSW-S.
Bellingham, Am. S. S.	Tacoma	Yokahoma	40 01 N	147 37 E	Mar. 11	8 a, 12	Mar. 14	29.08	SE	NW, 7	N	NW, 11	SE-S-WNW
San Diego Maru, Jap. M. S.	Elwood	do	34 04 N	154 40 E	do	10 a, 12	Mar. 15	29.35	E	W, 6	N	WNW, 10	SE-W.
Emilie L. D., Fr. S. S.	Portland	do	34 52 N	166 53 E	Mar. 12	7 p, 12	Mar. 12		SE	SE, 10	W	SE, 10	SE-WSW.
Do	do	do	34 33 N	162 04 E	Mar. 14	7 p, 14	Mar. 19	29.08	W	WNW, 9	N	WNW, 10	W-WNW.
Melville Dollar, Am. S. S.	Legaspi	Los Angeles	39 11 N	175 43 E	Mar. 12	Noon, 13	Mar. 13	29.36	SE	SE, 9	W	SE, 9	SE-S-W.
Eldena, Am. S. S.	San Pedro	Yokohama	31 23 N	162 05 E	Mar. 14	—, 14	Mar. 15	29.56	WSW	WSW, —	WNW	W, 9	SW-W.
Agura Maru, Jap. M. S.	Yokohama	Los Angeles	37 06 N	148 14 E	Mar. 17	8 p, 18	Mar. 17	29.60	SE	SSE, 9	NW	SSE, 9	SSE-W.
Pres. Taft, Am. S. S.	Victoria	Yokohama	39 48 N	146 45 E	Mar. 18	4 p, 18	Mar. 18	29.72	S	SE, 4		NNW, 11	
Grays Harbor, Am. S. S.	Tacoma	do	52 13 N	157 09 W	Mar. 21	3 a, 22	Mar. 22	28.52	ESE	W, 9	WSW	SW, 9	SSW-W.
Admiral Farragut, Am. S. S.	Seattle	Kodiak	59 54 N	145 20 W	Mar. 23	1 a, 23	Mar. 23	29.73	E	E, 10	E	E, 10	E-SW.
Everett, Am. S. S.	Hong Kong	San Francisco	34 10 N	148 25 E	do	6 p, 23	Mar. 26	28.42	SSE	S, 7	NW	SE, 9	
Emma Alexander, Am. S. S.	San Diego	Seattle	37 51 N	122 42 W	Mar. 24	6 p, 24	Mar. 25	29.93	WNW	NW, 5	NNW	NW, 9	Steady.
Grays Harbor, Am. S. S.	Tacoma	Yokohama	49 36 N	167 35 E	Mar. 29	2 a, 30	Mar. 31	29.54	S	SSE, 8	WSW	WSW, 9	WSW-SSE.

[1] Approximate.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

Atmospheric pressure.—During March, 1931, atmospheric pressure rose generally over that of February throughout the Aleutian region, the Gulf of Alaska, and along the greater part of the American coast and adjacent waters. The Aleutian cyclone remained central on the average, as in the preceding month, over and near the Peninsula of Alaska, with average pressure of 29.65 inches at Kodiak, where a rise of 0.42 inch occurred over the February mean.

The North Pacific anticyclone was in general less well developed than in February, owing to the more frequent intrusion upon its central area by cyclones from higher latitudes. In the main, however, it remained stable over a considerable region off the coast of the United States and in lower middle latitudes, and thence westward into east longitudes.

The following table gives barometric data for several island and coast stations in west longitudes, including Point Barrow on the Arctic Ocean.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, at indicated hours, North Pacific Ocean and adjacent waters, March, 1931*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow [1]	30.50	+0.35	30.90	12th [2]	30.10	24th.
Dutch Harbor [1]	29.76	+0.06	30.32	10th	28.94	3d.
St. Paul [1] [3]	29.81	+0.08	30.40	11th	29.22	4th.
Kodiak [1]	29.65	−0.04	30.30	9th	28.90	21st.
Midway Island [1]	30.00	−0.07	30.34	21st	29.62	27th.
Honolulu [4]	30.06	+0.02	30.15	3d	29.94	29th.
Juneau [4]	29.96	+0.02	30.51	6th	29.17	20th.
Tatoosh Island [4] [5]	30.06	+0.08	30.53	22d	29.47	11th.
San Francisco [4] [5]	30.13	+0.08	30.37	2d	29.79	4th.
San Diego [4] [5]	30.02	0.00	30.26	1st	29.74	25th.

[1] P. m. observations only in averages; a. m. and p. m. in extremes.
[2] And on the 13th.
[3] For 30 days.
[4] A. m. and p. m. observations.
[5] Corrected to 24-hour mean.

Cyclones and gales.—Cyclonic activity was less intense and gales as a consequence were less frequent over that half of the ocean east of 180° longitude than in February. In this region few winds were reported of higher force than 9. Of the exceptions, one was a south gale of force 11 experienced by the S. S. *Golden Sun* southwest of the Gulf of Alaska on the 3d, while the vessel was on the eastern edge of an Aleutian disturbance then centered about 5° south of Dutch Harbor. Another was an east gale of force 10 experienced by the S. S. *Admiral Farragut* in the upper waters of the Gulf of Alaska on the 23d, in connection with a cyclone then central over the eastern part of the Bering Sea.

Going westward from middle longitudes, however, seamen entered a zone of greatly increased storminess and, along the upper routes, of lessened visibility, especially during the early half of the month. From the central Aleutians southward to about 25° or 30° north latitude, and thence westward to the Kuril Islands and Japan, an area is inclosed over which more and severer gales occurred during the first 18 days of March than were experienced during the entire preceding month. After the 18th, storminess was scattered and relatively infrequent.

Along the western extent of the northern steamship routes storm to hurricane velocities were reported on the 2d, 4th, 5th, and 6th between 45° and 50° N., and 165° E. and 180°, in connection with the severest storm field of the month. The disturbance in this region, during the period of greatest intensification, was augmented by two LOWS, one from Siberia, the other from China. The latter left the continent on the 2d and after skirting the east coast of Japan lay east of the Kurils on the 5th. After the 6th the major storm seems to have abated in energy, since from the 7th to the 10th of March no winds exceeding force 10 were reported from its general field. The American S. S. *Bellingham*, westbound between Tacoma and Yokohama, passed through this storm, encountering heavy gales with snow from the 3d, when near 50° N., 165° E., until the 9th, when near 44° N., 156° E. On the 6th the ship was reported as "one mass of ice" from snow and sleet, and on the 7th as hove to on account of gales and thickness of the weather. An offshoot from this storm seems early to have gone eastward and southeastward as a moderate cyclone until the 9th, on which date it was central near 39° N., 142° W. Later it moved northeastward and entered the coast of British Columbia on the 12th.

On the 9th a LOW developed east of Taiwan and proceeded northeastward. By the afternoon of the 12th it had acquired sufficient energy east of northern Japan so that the S. S. *Bellingham*, closely following its recent experience with blinding snow squalls, underwent further stiff weather which culminated in a northwesterly gale of force 11 southeast of Yezo. During the 12th to 14th, connected with the storm development, as it covered a widening field, gales of force 8 to 10 occurred over a considerable expanse of water between latitudes 25° and 40° N. and extending as far east as the one hundred and seventy-fifth meridian of east longitude.

On the 18th, in 39° N., 146° E., the S. S. *President Taft* encountered gales which reached a maximum force of 11 from westnorthwest. The heaviest forces occurred during a rapid rise in pressure following the passage of a moderate disturbance.

Off the central California coast local gales, rising at times to force 9, were reported on the 4th, 5th, and 24th. These were produced by the strong gradients existing between neighboring inland depressions and the eastern ridges of the North Pacific HIGH abutting on the coast.

In the Gulf of Tehuantepec strong northers, maximum force 10, were encountered on the 8th to 10th, during the prevalence of an anticyclone over the southern part of the United States and the Gulf of Mexico.

Winds at Honolulu.—At Honolulu the prevailing wind this March was from the east, but kona winds occurred during 25 per cent of the hours, being unusually frequent for the month. The maximum velocity was 26 miles an hour from the northeast on the 31st. The average hourly velocity was 6.7 miles, which, according to the Honolulu record, is the lowest for the month since the opening of the station in 1904.

Fog and smoke.—There was very little change in the low frequency and scattered formation of fog over most of the ocean over that of the preceding February, the percentage of days with the phenomenon, as reported, not exceeding 10 for the most frequented areas to the westward of the one hundred and thirtieth meridian of west longitude. Along the California coast, however,

fog showed a decided increase in frequency, with a maximum occurrence on about 40 per cent of the days over the region within approximately 100 miles of San Francisco.

On several days of the month, particularly on the 8th and 9th and the 18th to 24th, vessels reported smoke from burning brush which somewhat impeded navigation close on the coasts of Guatemala and Salvador. This most generally prevailed in the early morning, being carried inland by the sea breeze about 8:30 a. m.

THE FIJI ISLANDS STORM OF FEBRUARY 17–MARCH 2, 1931

By WILLIS E. HURD

In an official report dated March 10, 1931, to the Secretary of State, the American consul at Suva, Fiji, Quincy F. Roberts, begins thus:

> The Fiji Islands, during the period February 17 to March 2, 1931, experienced a hurricane and floods said to be the worst in the history of the colony.

Unfortunately there are not yet exact data at hand from which to determine whether one or two cyclones hovered about the islands during this period, although it was not until the 3d of March that westerly winds arrived at Suva, near the southeastern extremity of the largest island, which indicated by the circulation that the center was receding southward. According to newspaper reports, two hurricanes devastated the islands, one about the 21st and 22d of February and the other on the 1st and 2d of March. These are the four days on which, during 14 days of stormy weather with periods of abnormally heavy rainfall, the meteorological conditions were apparently most violent. The destruction to property, including buildings and cattle, and to such crops as breadfruits and sugarcane, as well as the loss of approximately 200 lives, was probably confined to the principal island, Viti Levu. Most of the loss of life was by drowning in the extraordinary floods produced on the eastern slopes of the island, where many villages were wholly destroyed.

While the gales did not exceed force 9 at Suva, according to the consular report, yet hurricane velocities occurred in various districts, expecially in the north and west, where the cyclonic force seems to have centered, and also at sea. In some localities both east and west of the principal mountain range the flood stages in the rivers were the highest of record. The heaviest rainfall reported occurred at Nandarivatu, on the western slope of the range, near Mount Victoria, where 84 inches fell in less than a week. The heavy precipitation occurred to the east of the storm center and quite apparently in the forward left-hand quadrant, as the cyclone seemingly moved southwestward during the occurrence of most of these excessive rains.

The lowest barometer reading reported was 28.70 inches, occurring at Lautoka, on the northwest of Viti Levu, at midnight of the 21st. Shipping was much hampered by the heavy seas, the high winds, and the thick weather, which prevented a landing. The steamship *Golden Harvest* occupied 15 days in making the trip of 1,500 miles between Brisbane and Fiji, and the steamship *Malake* spent three days during the 21st to 24th in steaming the 50 or 60 miles between the Fijian ports of Levuka and Suva, harbor lights being obscured by the blinding rain, and the ship also being driven off her course by the terrific winds and seas.

BUCKET OBSERVATIONS OF SEA-SURFACE TEMPERATURES

By GILES SLOCUM

STRAITS OF FLORIDA AND CARIBBEAN SEA

The temperatures herein published are the means of the average temperatures for the four quarters of the month, except that, in the case of the 5° subdivisions of the Caribbean Sea, the figures shown are the simple means of the observed temperatures with the entire month taken as a unit. Table 1 shows the lengths of the quarters for each length of month.

Table 2 shows the average temperature for the Caribbean Sea and the Straits of Florida for March of each year from 1919 to 1930, inclusive, and Table 3 summarizes the temperature for the month in the same areas, including the departures of the March, 1930, means from the 11-year means for March (1920–1930), and the changes from the temperatures for the preceding month of February, 1930.

The chart shows the number of observations taken during the month of March, 1930, within each 1° square; the mean temperature of the Straits of Florida, and of each 5° [1] subdivision of the Caribbean Sea: The 11-year means (1920–1930) for these areas; and the local mean time corresponding to Greenwich mean noon, at which time the mariners are instructed to make the temperature readings.

March normally brings the turn of the season in the temperature of the surface water in the Caribbean Sea and the Straits of Florida, the first quarter showing, in both bodies of water, the lowest average temperatures of any winter quarter-month, the means for the 11 years in this quarter-month being 78.2° in the Caribbean Sea and 73.9° in the Straits of Florida.

The temperature rises noticeably during the last days of March. This effect has, in the majority of years for which observations are available, made March warmer than February, more than compensating for the downward trend of the average temperature, which persists until some days after the month begins.

The seasonal lag is thus between 70 and 80 days after the winter solstice, as compared with the 15 to 40 day lag of air temperatures along the island and continental coast lines of the region.

Reference to Table 3 will show that the temperatures rose markedly from the February values, which were close to normal, to rather high figures for March in both the Caribbean Sea and the Straits of Florida. The third quarter was, in the Caribbean, as warm as the mean for the corresponding part of April, with the abnormally high readings occurring principally within the western half of the sea and south of the twentieth parallel.

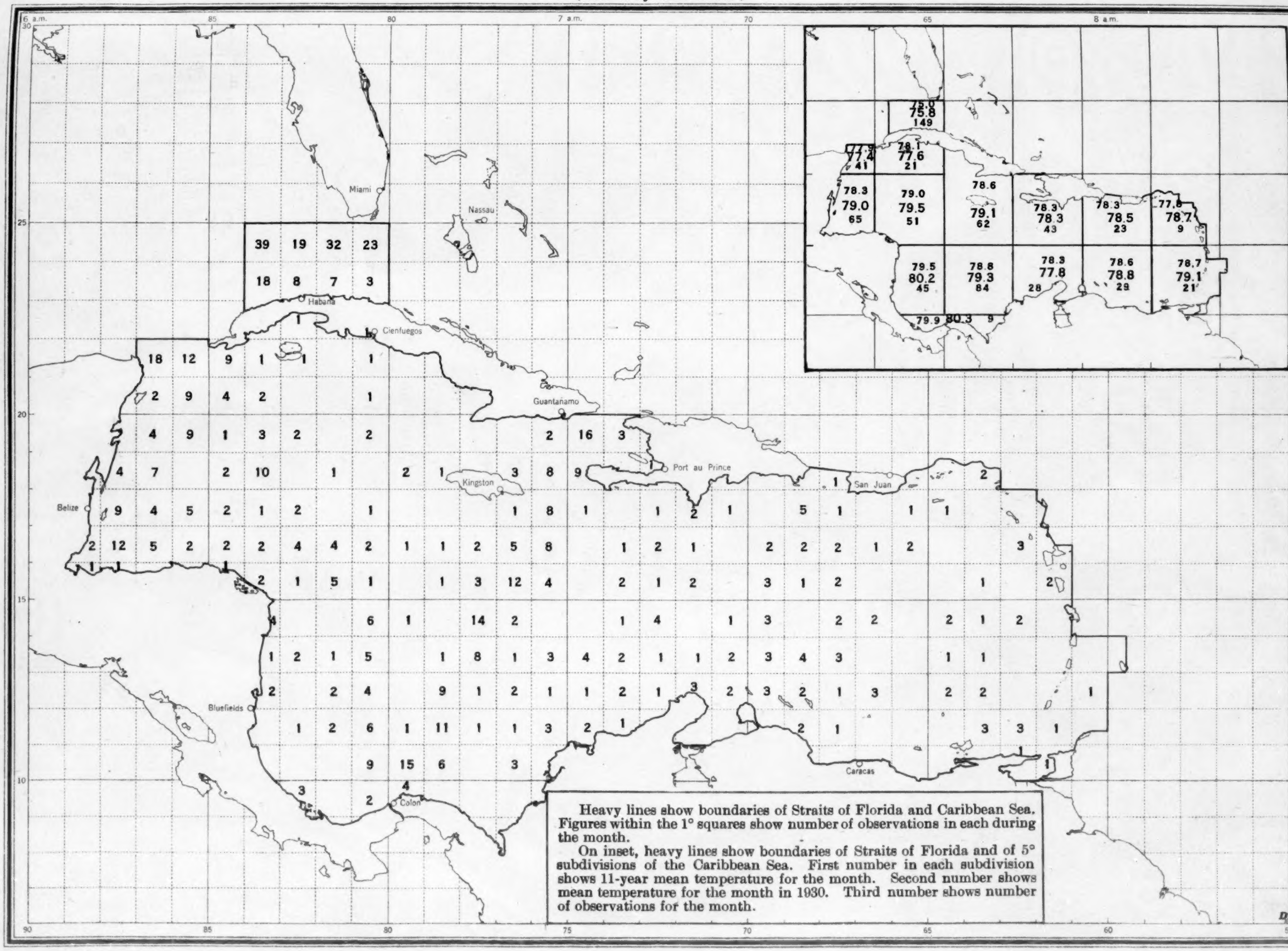
TABLE 1.—*Lengths of "Quarter-months" used in computing mean sea-surface temperatures*

Length of month	Days of month included in quarter			
	I	II	III	IV
28 days	1–7	8–14	15–21	22–28
29 days	1–7	8–14	15–21	22–29
30 days	1–7	8–15	16–22	23–30
31 days	1–7	8–15	16–23	24–31

[1] In three cases, as indicated on the chart, the observations for small, little traveled, and unimportant areas at the outer limits of the Caribbean Sea have been treated as parts of contiguous 5° subdivisions.

Distribution of Greenwich Mean Noon Bucket Observations of Sea-Surface Temperatures, March, 1930

(Plotted by Giles Slocum)



Heavy lines show boundaries of Straits of Florida and Caribbean Sea. Figures within the 1° squares show number of observations in each during the month.

On inset, heavy lines show boundaries of Straits of Florida and of 5° subdivisions of the Caribbean Sea. First number in each subdivision shows 11-year mean temperature for the month. Second number shows mean temperature for the month in 1930. Third number shows number of observations for the month.

TABLE 2.—*Mean sea-surface temperatures in the Caribbean Sea and the Straits of Florida for March (1919–1930)*

Year	Caribbean Sea		Straits of Florida	
	Number of observations	Mean (°F.)	Number of observations	Mean (°F.)
1919 [1]	26	78.3	15	78.2
1920	139	78.9	20	72.2
1921	194	78.2	53	75.8
1922	170	78.7	75	75.9
1923	346	77.6	110	76.0
1924	318	78.3	84	73.5
1925	247	78.6	73	75.0
1926	434	79.2	129	73.9
1927	347	79.1	126	76.0
1928	360	79.0	106	74.7
1929	457	78.6	146	76.1
1930	531	78.9	149	75.8
Mean (1920–1930)		78.6		75.0

[1] Not used in computations because of insufficient data available.

TABLE 3.—*Mean sea-surface temperatures (°F), and number of observations, March, 1930*

Quarter	Period	Caribbean Sea				Straits of Florida			
		Number of observations	Mean	Departure from 11-year mean (1920–1930)	Change from preceding month	Number of observations	Mean	Departure from 11-year mean (1920–1930)	Change from preceding month
			°F.	°F.	°F.		°F.	°F.	°F.
I	1–7	114	78.0			31	74.7		
II	8–15	145	78.8			38	76.8		
III	16–23	123	79.6			40	75.8		
IV	24–31	149	79.2			40	75.9		
Month		531	78.9	+0.3	+0.5	149	75.8	+0.8	+1.2

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, March, 1931

(For description of tables and charts, see REVIEW, January, p. 50)

Section	Temperature								Precipitation					
			Monthly extremes								Greatest monthly		Least monthly	
	Section average	Departure from the normal	Station	Highest	Date	Station	Lowest	Date	Section average	Departure from the normal	Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	49.9	−6.0	2 stations	78	[1] 19	Valley Head	22	4	3.80	−2.16	Seven Hills	7.26	Tuskegee	1.78
Arizona	53.4	+0.5	Le Sage	100	22	Alpine	−12	26	0.23	−0.85	Henry's Camp	1.66	29 stations	0.00
Arkansas	47.5	−5.1	Okay	85	13	Dutton	16	10	4.21	−0.47	Wynne	6.83	Portland	2.73
California	53.2	+2.6	Mecca	100	22	Ellery Lake	−2	29	1.47	−2.38	Crescent City	10.87	9 stations	0.00
Colorado	32.2	−2.4	3 stations	81	22	Spicer	−25	27	1.17	−0.21	La Veta Pass	4.37	Las Animas	0.18
Florida	59.5	−6.1	Fort Lauderdale	86	29	Mount Pleasant	26	5	5.23	+2.11	Garniers	9.25	Carrabelle	2.40
Georgia	51.2	−5.3	Quitman	84	27	Clayton	19	5	2.96	−2.02	Clayton	7.25	Goat Rock	1.46
Idaho	35.9	0.0	Glens Ferry	77	22	Felt	−20	6	2.40	+0.81	Roland	7.54	Ashton	0.20
Illinois	37.3	−3.5	Mascoutah	69	13	2 stations	12	11	2.75	−0.30	Anna	4.57	Hoopeston	1.68
Indiana	36.7	−4.0	Rome	68	23	Goshen	1	13	3.03	−0.72	Shoals	5.37	Noblesville	1.64
Iowa	34.9	+0.3	Baxter	64	13	Decorah	5	30	1.68	−0.08	Fairfield	4.18	Alton	0.15
Kansas	39.1	−4.6	St. Francis	85	18	Goodland	−3	27	2.41	+0.92	Trousdale	4.77	Irene	0.90
Kentucky	41.5	−4.8	Williamsburg	73	24	3 stations	18	[1] 3	3.68	−1.01	Quicksand	5.79	Cold Spring	2.11
Louisiana	54.3	−6.4	Melville	84	14	Robeline	25	10	4.15	−0.59	Pearl River	6.55	Logansport	1.46
Maryland-Delaware	39.3	−3.7	2 stations	65	25	2 stations	14	11	4.38	+0.95	Millsboro, Del	5.97	Picardy, Md	3.22
Michigan	30.2	+0.6	Ganges	59	23	Wolverine	−14	11	2.05	−0.12	Deer Park	3.75	St. Ignace	0.78
Minnesota	28.5	+2.2	Beardsley	63	20	2 stations	−12	15	1.23	+0.15	Roseau	2.12	Pigeon River Bridge	0.21
Mississippi	51.2	−5.6	6 stations	80	[1] 14	Batesville	24	10	4.63	−1.14	Pontotoc	7.95	Lake	2.35
Missouri	39.5	−4.4	5 stations	70	[1] 13	Unionville	10	4	3.02	0.00	Poplar Bluff	6.03	Edgerton	1.23
Montana	32.7	+2.6	Billings	74	21	Adel (near)	−22	27	0.80	−0.12	2 stations	4.34	2 stations	T.
Nebraska	34.5	−1.4	Benkelman	78	22	Mullen	−14	27	1.74	+0.64	Curtis	5.25	Hull (near)	0.38
Nevada	42.1	+1.2	Las Vegas	92	22	San Jacinto	−3	17	0.48	−0.40	Lewers Ranch	2.80	3 stations	0.00
New England	34.7	+2.4	Adams, Mass	64	28	Pittsburg (a), N. H.	−14	3	3.78	+0.52	Falmouth, Mass	8.14	Bethlehem, N. H	0.72
New Jersey	39.2	+0.7	2 stations	64	[1] 25	Belleplain	12	14	4.14	+0.30	Chatham	6.06	Layton	2.60
New Mexico	40.5	−2.5	do	89	[1] 22	Selsor Ranch	−26	8	0.99	+0.13	Gallinas Planting Station.	3.86	3 stations	0.00
New York	33.8	+1.7	Mohonk Lake	68	27	North Lake	−3	3	2.27	−0.74	Cutchogue	6.96	Sperryville	0.52
North Carolina	44.4	−5.5	2 stations	77	14	Mount Mitchell	1	5	3.66	−0.54	Mount Mitchell	7.82	Marshall	1.28
North Dakota	25.7	+1.6	Portal	63	31	Towner	−24	26	0.94	+0.24	Bowman	2.33	Westhope	0.07
Ohio	36.2	−3.1	Ironton	66	24	Canfield	11	11	2.14	−1.28	2 stations	3.97	London	1.17
Oklahoma	45.6	−5.4	Hollis	85	12	Hooker	−2	31	3.08	+1.24	Buffalo	5.08	Kenton	1.02
Oregon	42.2	+1.4	2 stations	80	2	Lake	−3	7	4.06	+1.43	Valsetz	29.54	Lake	0.57
Pennsylvania	36.3	−1.4	Gettysburg	69	27	3 stations	10	[1] 3	2.96	−0.48	New Park	5.72	Montrose	0.70
South Carolina	48.8	−5.8	Garnett	78	[1] 14	Caesar's Head	18	5	2.98	−0.97	Crescent	5.29	Darlington	1.39
South Dakota	31.9	+0.3	Cedar View	72	22	Lead	−16	[1] 26	1.16	+0.11	Dumont	3.17	Onaka	0.21
Tennessee	44.1	−5.3	Clarksville	72	13	Elkmont	11	5	3.79	−1.55	Celina	5.44	Johnson City	1.28
Texas	52.7	−6.0	Mission	95	26	Miami	4	27	2.50	+0.42	Bon Wier	7.30	2 stations	T.
Utah	37.8	−0.4	St. George	85	21	Woodruff	−11	27	0.82	−0.71	Silver Lake	3.33	Escalanti	0.00
Virginia	40.7	−5.2	Diamond Springs	69	25	Burkes Garden	15	18	3.56	−0.10	Onley	5.90	Damascus	1.54
Washington	42.0	+1.1	Nespelem	79	12	Bumping Lake	6	4	5.96	+1.98	Big Four	29.94	Oroville	0.43
West Virginia	37.4	−5.3	Romeny	68	27	Pickens	10	13	3.52	−0.26	Pickens	7.95	Upper Tract	1.90
Wisconsin	30.4	+1.1	3 stations	58	[1] 12	Downing	−18	1	1.73	−0.01	Racine	5.71	Chippewa P. K. Reservoir.	0.42
Wyoming	29.0	−0.6	Thermopolis	71	21	Foxpark	−33	6	1.04	−0.04	Bechler River	4.93	Dubois	0.10
Alaska (Feb.)	14.3	+6.9	Tree Point	53	3	Pilot Station	−43	27	2.27	+0.38	Ketchikan	16.15	Barrow	0.02
Hawaii	70.3	+1.0	Kaanapali	90	[1] 23	Volcano Observatory	46	6	3.98	−4.92	Kawainui (lower)	17.99	Launiupoko	0.00
Porto Rico	75.9	+2.6	Dorado	96	17	Jayuya	50	15	2.67	−0.91	Barros	9.40	Santa Isabel	0.13

[1] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1931*

District and station	Elevation of instruments: Barometer above sea level	Thermometer above ground	Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Departure from normal	Days with .01, or more	Wind: Total movement	Prevailing direction	Maximum velocity: Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							36.4	+3.6										78	4.10	+0.7										6.5		
Eastport	76	67	85	29.82	29.91	−0.02	33.8	+4.9	50	23	38	24	7	30	21	32	28	80	2.80	−1.0	13	9,179	ne.	56	e.	9	8	0	23	7.7	15.1	0.0
Greenville, Me.	1,070	6		28.74	29.94		30.2		52	23	38	4	3	22	36				2.26		11	4,634	n.	23		5	7	7	17		17.8	
Portland, Me.	103	82	117	29.80	29.93	−.03	36.6	+4.8	53	31	42	24	7	32	18	32	27	71	6.78	+2.9	11	6,425	n.	32	e.	8	12	4	15	5.8	10.1	0.0
Concord	289	70	79	29.57	29.90	−.10	35.7	+4.9	54	22	44	13	3	28	30				3.10	+0.1	9	4,232	n.	33	ne.	8	13	8	10	5.1	10.0	0.0
Burlington	403	11	48	29.48	29.94	−.06	32.6	+3.5	53	24	39	9	3	26	28				1.82	−0.2	11	5,045	n.	29	se.	8	5	6	20	7.4	10.1	T.
Northfield	876	12	60	28.97	29.95	−.05	30.8	+3.9	53	27	40	−1	3	21	38	27	25	84	1.00	−0.7	11	3,462	n.	22	n.	18	4	13	14	6.7	19.6	T.
Boston	125	106	165	29.74	29.88	−.09	39.3	+3.7	57	29	45	27	3	34	18	35	29	72	4.66	+1.1	12	6,668	nw.	32	ne.	26	8	11	12	6.1	7.3	0.0
Nantucket	12	14	90	29.82	29.83	−.15	37.8	+2.8	52	29	42	30	3	34	13	36	33	86	6.30	+2.6	13	13,227	ne.	50	ne.	4	7	8	16	7.1	12.3	0.0
Block Island	26	11	46	29.82	29.85	−.13	37.4	+2.0	50	29	42	28	14	33	14	35	32	84	4.08	+0.2	10	13,273	w.	48	n.	26	8	8	15	6.4	8.5	0.0
Providence	160	215	251	29.70	29.88	−.10	38.8	+3.1	53	24	45	26	3	32	23	34	30	75	4.14	+0.6	12	9,188	nw.	34	n.	26	10	8	13	5.7	10.2	0.0
Hartford	159	122		29.72	29.90	−.09	38.6	+3.6	59	24	45	23	3	32	25				4.26	+0.4	11		nw.				6	8	17	6.7	6.0	0.0
New Haven	106	74	153	29.77	29.89	−.10	39.0	+3.2	56	27	45	26	3	33	20	35	30	73	5.27	+1.2	12	7,480	n.	31	n.	26	7	11	13	6.3	6.3	0.0
Middle Atlantic States							40.1	−0.7										71	3.61	+0.1										7.2		
Albany	97	107	115	29.82	29.93	−.08	37.6	+4.9	57	24	44	18	3	31	28	32	26	67	1.48	−1.1	10	5,011	n.	26	ne.	26	8	10	13	6.3	4.7	0.0
Binghamton	871	10	84	28.97	29.92	−.10	34.7	+2.1	57	27	41	19	3	28	29				1.46	−1.2	13	4,526	nw.	21	se.	24	1	4	26	8.8	5.3	0.0
New York	314	414	454	29.55	29.90	−.10	40.5	+2.8	60	27	47	20	11	34	22	35	29	69	4.74	+1.1	11	11,640	nw.	51	nw.	5	4	8	19	7.6	1.0	0.0
Bellefonte	1,050	5	36	28.79	29.93		34.0		56	27	41	19	3	27	30	30	27	78	1.61		13		w.				0	7	24	8.8	4.7	0.0
Harrisburg	374	94	104	29.54	29.95	−.08	38.7	−0.2	57	23	44	25	3	33	20	34	27	66	3.72	+0.7	13	5,801	w.	24	w.	5	5	7	19	7.3	2.9	0.0
Philadelphia	114	123	367	29.79	29.92	−.10	42.3	+1.5	61	27	48	29	11	36	21	36	29	62	3.97	+0.6	12	10,656	nw.	37	nw.	5	3	9	19	7.5	0.8	0.0
Reading	325	81	98	29.57	29.93		39.4	−0.6	58	27	46	27	3	33	23	34	29	70	4.35	+0.8	11	5,510	w.	38	e.	8	7	9	15	7.1	3.2	0.0
Scranton	805	111	119	29.04	29.93	−.09	36.7	+1.0	60	27	43	22	3	31	28	32	28	74	2.20	−1.0	11	5,155	ne.	30	e.	8	3	8	20	7.5	3.2	0.0
Atlantic City	52	37	172	29.83	29.89	−.13	40.0	+1.4	57	29	45	27	11	35	21	36	32	75	5.19	+1.6	15	13,768	w.	54	e.	8	5	7	19	7.0	2.2	0.0
Cape May	17	13	49				40.5	−0.3	57	25	46	28	11	35	20	37	34	82	5.92	+2.2	16		nw.				4	11	16		7.3	0.0
Sandy Hook	22	10	55	29.86	29.87		39.6		54	27	44	30	11	35	16	35	31	74	3.94	−0.1	11	12,307	nw.	50	e.	8	7	7	17	6.3	0.1	0.0
Trenton	190	159	183	29.69	29.90		39.7	+0.6	59	27	46	26	3	33	22	34	29	70	3.24	−0.2	12	9,011	nw.	38	e.	8	4	8	19	7.4	0.2	0.0
Baltimore	123	100	215	29.79	29.92	−.11	41.9	−0.4	60	25	48	27	11	36	21	37	31	68	4.62	+0.9	11	8,638	nw.	35	ne.	8	6	9	16	6.8	10.0	0.0
Washington	112	62	85	29.81	29.94	−.10	41.3	−1.3	60	25	48	26	11	35	24	35	28	63	3.50	−0.2	14	6,158	nw.	30	nw.	10	5	12	14	6.6	T.	0.0
Cape Henry	18	8	54	29.87	29.80		42.8	−3.8	61	8	48	29	13	38	23	39	36	78	4.14	+0.3	13	11,066	nw.	44	n.	23	5	13	13	6.6	T.	0.0
Lynchburg	681	153	188	29.18	29.94	−.11	42.2	−5.1	61	26	49	30	21	35	27	36	30	65	3.75	+0.2	11	5,631	nw.	30	n.	19	7	5	19	6.7	4.3	0.0
Norfolk	91	170	205	29.82	29.92	−.11	44.2	−4.0	63	25	51	28	12	38	26	39	34	73	2.74	−1.0	13	10,046	n.	35	n.	3	5	8	18	6.9	T.	0.0
Richmond	144	11	52	29.78	29.94	−.10	42.3	−4.9	63	25	50	27	13	34	27	38	34	77	2.94	−0.7	10	6,396	nw.	29	w.	8	4	11	16	6.8	T.	0.0
Wytheville	2,304	49	55	27.50	29.94	−.11	36.7	−5.6	55	14	44	20	18	30	35	32	27	74	3.16	−0.3	12	5,151	nw.	26	w.	8	3	10	18	7.7	8.7	0.8
South Atlantic States							49.6	−4.1										68	3.51	−0.2										5.2		
Asheville	2,253	80	104	27.56	29.96	−.10	41.1	−3.8	65	13	50	21	5	32	39	34	28	68	2.50	−1.4	8	7,658	nw.	30	nw.	10	9	10	12	5.8	5.8	0.0
Charlotte	779	55	62	29.08	29.93	−.12	46.5	−3.9	68	14	56	28	12	37	31	39	32	63	4.41	+0.2	8	4,813	n.	29	sw.	8	10	10	11	5.4	4.7	0.0
Greensboro	886	6	56	28.97	29.94		42.6		68	14	53	21	11	32	33	36	32	73	3.53		12	6,787	n.	27	w.	9	5	12	14	6.4	3.0	0.0
Hatteras	11	5	50	29.88	29.89	−.15	47.6	−4.4	64	29	53	34	13	42	23	43	40	79	5.48	+1.2	12	11,615	nw.	52	nw.	3	9	10	12	5.6	T.	0.0
Raleigh	376	103	146	29.52	29.93	−.12	46.2	−4.0	68	14	55	28	11	38	28	40	33	66	3.15	−0.7	8	6,895	nw.	27	w.	9	9	7	15	6.1	0.5	0.0
Wilmington	78	81	91	29.86	29.95	−.10	50.1	−3.2	73	14	59	31	12	41	30	43	37	67	3.06	−0.1	11	5,419	w.	25	w.	25	13	9	9	5.0	0.1	0.0
Charleston	48	11	92	29.80	29.94	−.12	53.8	−3.6	75	15	61	35	5	46	21	47	41	69	2.88	−0.1	7	8,045	w.	37	se.	21	15	6	10	4.6	0.0	0.0
Columbia, S. C.	351	41	57	29.56	29.95	−.11	49.8	−5.4	70	14	59	32	5	41	29	42	35	63	2.96	−0.4	8	5,639	w.	28	sw.	8	11	8	12	5.3	0.3	0.0
Due West	711	10	55	29.19	29.98		47.2		68	14	57	27	5	37	32				3.01		8	7,476	w.	36	w.	8	9	10	12	5.7	0.8	0.0
Greenville, S. C.	1,039	139	146	28.82	29.93		46.8	−3.1	67	14	56	29	5	38	29	40	33	66	4.63	−0.5	10	7,064	ne.	36	ne.	31	12	10	9	5.0	T.	0.0
Augusta	182	62	77	29.74	29.94	−.12	51.6	−4.4	77	28	62	32	5	41	37	45	39	69	2.14	−2.0	6	4,786	nw.	27	w.	8	12	8	11	5.0	0.0	0.0
Savannah	65	150	194	29.87	29.94	−.12	54.8	−4.2	74	15	64	36	5	46	25	47	41	68	2.62	−0.4	7	9,494	w.	40	w.	8	17	5	9	4.1	0.0	0.0
Jacksonville	43	209	245	29.92	29.97	−.09	57.8	−4.8	78	28	66	38	10	49	25	50	44	67	4.69	+1.8	7	8,934	w.	60	se.	28	16	8	7	4.1	0.0	0.0
Florida Peninsula							64.5	−5.4										76	5.87	+3.8										4.8		
Key West	22	10	64	29.97	29.99	−.06	67.5	−5.1	82	1	73	53	11	62	24	62	59	78	4.44	+3.0	9	8,177	n.	49	w.	3	11	14	6	4.7	0.0	0.0
Miami	25	124	168	29.97	30.00	−.09	65.2	−5.0	82	29	72	45	10	58	27	59	55	74	6.10	+3.9	8	7,329	nw.	34	sw.	31	10	11	10	5.4	0.0	0.0
Tampa	35	79	197	29.96	30.00	−.07	60.8	−6.0	81	26	69	44	6	53	27	54	50	75	7.07	+4.6	8	7,985	nw.	36	e.	28	14	7	10	4.8	0.0	0.0
Titusville	44	5		29.94	29.99		60.8		80	15	71	39	10	51	32				4.91		8		w.				16	13	2	4.5	0.0	0.0
East Gulf States							52.2	−5.4										68	4.02	−1.2										4.9		
Atlanta	1,173	190	198	28.70	29.95	−.11	46.7	−5.3	68	13	55	29	10	38	26	39	32	62	3.46	−1.8	9	8,603	nw.	33	nw.	9	10	9	12	5.7	T.	0.0
Macon	370	78	87	29.56	29.96	−.10	50.8	−5.9	74	14	62	29	5	40	37	42	33	58	2.39	−2.6	9	5,242	nw.	28	se.	27	10	9	12	5.1	0.0	0.0
Thomasville	273	49	103	29.68	29.98	−.08	56.0	−4.2	80	27	66	34	10	46	30	47	40	64	3.73	−0.4	10	6,231	nw.	43	se.	28	10	11	10	4.9	0.0	0.0
Apalachicola	36	11	51	29.95	29.99		56.6		74	15	64	38	10	49	25	51	47	75	5.56	+1.3	9	6,984	nw.	51	e.	28	14	13	4	4.1	0.0	0.0
Pensacola	56	149	185	29.94	30.00	−.06	55.0	−5.3	70	25	61	37	4	49	23	50	47	79	4.80	0.0	10	10,422	w.	48	se.	21	12	10	9	4.7	0.0	0.0
Anniston	741	9	57	29.20	30.00	−.06	47.8	−4.7	72	24	59	25	5	37	34				3.31	−2.3	9	4,631	nw.	22	w.	8	13	7	11	5.1	T.	0.0
Birmingham	700	11	48	29.21	29.99	−.07	49.0	−6.4	71	24	59	28	10	39	30	41	35	67	2.78	−2.9	10	5,865	nw.	32	se.	27	11	9	11	5.1	0.1	0.0
Mobile	57	125	161	29.93	29.99	−.07	55.0	−4.7	74	19	63	37	4	47	27	49	44	74	6.35	+0.4	10	7,666	nw.	48	se.	27	12	9	10	4.8	0.0	0.0
Montgomery	223	100	112	29.74	30.00	−.06	52.4	−5.4	73	24	62	34	10	43	27	44	36	62	2.88	−3.1	11	5,210	nw.	27	w.	31	11	12	8	4.8	0.0	0.0
Corinth	469	6					47.5		69	13	58	26	10	38	35				4.14		12		se.				6	13	12		T.	0.0
Meridian	875	87	95	29.59	29.99	−.06	51.0	−6.1	72	19	60	31	5	42	34	43	36	64	3.73	−1.5	10	5,138	w.	28	se.	7	17	4	10	4.5	T.	0.0
Vicksburg	247	65	73	29.74	30.03	−.01	52.6	−5.9	77	19	62	34	9	43	33	44	38	65	4.45	−1.1	11	5,977	nw.	26	w.	7	14	7	10	4.9	0.0	0.0
New Orleans	53	76	84	29.95	30.01	−.03	57.5	−5.3	77	14	65	40	8	50	23	51	46	73	4.83	+0.1	10	4,937	w.	22	e.	30	13	7	11	5.1	0.0	0.0
West Gulf States							53.7	−5.5										68	2.85	+0.1										4.7		
Shreveport	249	77	93	29.74	30.02	.00	52.2	−6.1	79	23	62	32	28	42	32	47	43	78	3.34	−0.8	10	5,236	se.	24	w.	7	9	12	10	5.4	0.0	0.0
Bentonville	1,303	11	44	28.59	29.98	−.03	42.7	−4.6	66	13	51	23	28	34	31				3.14		7	4,562	nw.	24	s.	5	16	5	10		4.7	0.0
Fort Smith	457	79	94	29.51	30.00	−.01	47.2	−5.4	69	12	56	25	28	38	33	40	34	67	2.78	−0.2	9	7,376	e.	34	w.	7	8	9	14	6.2	T.	0.0
Little Rock	357	136	153	29.61	30.00	−.03	48.2	−4.8	70	23	56	31	29	40	29	41	33	61	4.47	−0.2	9	7,670	n.	38	w.	7	7	13	11	5.9	T.	0.0
Austin	605	136	148	29.38	30.02		55.8	−4.9	83	23	68	32	28	44	33	48	42	68	3.35	+1.0	8	7,273	s.	36	nw.	30	18	7	6	3.6	0.0	0.0
Brownsville	57	83	100	29.95	30.01		63.7	−4.5	82	20	72	40	9	55	32	56	51	72	1.19	−0.1	2	8,328	se.	33	se.	13	12	14	5	4.6	0.0	0.0
Corpus Christi	20	11	78	30.00	30.02	+.04	61.2	−3.8	79	30	70	36	9	53	34	55	50	71	2.45	+0.8	6	9,155	se.	32	nw.	30	11	11	9	4.8	0.0	0.0
Dallas	512	220	227	29.46	30.02		50.8		75	12	60	27	28	42	30				3.29	+0.4	8	10,948	w.	30	nw.	8	15	7	9	4.1	0.5	0.0
Fort Worth	670	106	114	29.20	30.01	+.03	51.8	−5.9	77	12	62	28	28	42	28	45	38	64	4.20	+1.9	9	7,010	nw.	28	nw.	27	10	9	12	5.6	T.	0.0
Galveston	54	106	114	30.00	30.06	+.05	56.0	−6.4	72	20	62	35	28	50	29	52	48	78	2.01	−0.7	8	8,841	se.	34	nw.	6	17	3	11	4.3	0.0	0.0
Groesbeck	461	11	56	29.52	30.02		52.0		80	23	62	30	28	42	33				2.92	+0.3	10	8,913	nw.	31	sw.	5	14	8	9	4.8	0.0	0.0
Houston	138	292	314	29.80	30.04		56.0	−7.3	78	23	65	33	28	47	29				2.45	−1.0	9	9,964	nw.	37	se.	20	13	9	9	4.5	0.0	0.0
Palestine	510	64	72	29.49	30.03	+.03	51.7	−7.4	81	23	62	28	28	42	30	45	39	68	3.39	−0.1	12	6,389	nw.	26	nw.	27	14	4	13	4.9	T.	0.0
Port Arthur	34	58	66	29.99	30.03		56.0		74	27	64	34	28	48	36				2.33	−0.9	7	6,767	s.	29	nw.	30	14	8	9	4.5	0.0	0.0
San Antonio	693	242	301	29.28	30.01	+.03	58.0	−4.8	84	23	69	32	7	47	29	40	41	58	2.06	+0.2	8	9,947	nw.	44	nw.	30	19	9	3	3.3	0.0	0.0
Taylor	571	38	51	29.45	30.06	+.07	54.6	−5.1	83	23	67	30	28	42	33				2.48	+0.4	9	6,967	nw.	29	sw.	23	17	9	5	3.8	T.	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1931*—Continued

District and station	Elevation of instruments: Barometer above sea level	Thermometer above ground	Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Departure from normal	Days with .01, or more	Wind: Total movement	Prevailing direction	Maximum velocity: Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Ohio Valley and Tennessee							39.9	−4.3										73	2.78	−1.4										7.6		
Chattanooga	762	190	215	29.15	29.97	−0.09	46.2	−5.0	67	24	55	29	5	38	30	39	31	60	4.61	−1.2	12	6,720	nw.	38	se.	27	9	11	11	5.6	0.2	0.0
Knoxville	995	102	111	28.89	29.98	−.10	44.6	−4.1	67	24	53	27	5	36	34	38	32	67	2.73	−2.3	10	5,589	sw.	20	sw.	8	6	9	16	6.5	0.4	0.0
Memphis	399	76	97	29.55	29.98	−.06	47.1	−5.2	67	13	54	33	4	40	24	41	34	65	3.23	−2.0	11	7,045	sw.	37	sw.	7	8	6	17	6.4	T.	0.0
Nashville	546	168	191	29.40	30.00	−.05	44.2	−5.0	67	13	52	27	5	36	31	39	33	68	3.49	−1.6	12	7,686	nw.	32	w.	24	8	8	15	6.1	1.2	0.0
Lexington	989	193	230	28.91	30.00	−.05	37.8	−5.9	62	14	45	21	10	31	28				3.19	−1.1	11	9,022	w.	36	w.	25	5	8	18	6.8	3.9	0.0
Louisville	525	188	234	29.40	30.00	−.05	40.1	−5.3	65	14	47	27	11	33	22	36	31	72	2.83	−1.6	9	7,850	n.	35	sw.	7	5	7	19	7.4	2.4	0.0
Evansville	431	76	116	29.51	29.99	−.05	41.2	−4.7	63	13	48	28	2	34	25	37	32	74	3.55	−0.6	10	7,288	n.	35	w.	24	3	9	19	7.5	1.2	0.0
Indianapolis	822	194	230	29.06	29.97	−.07	36.5	−3.5	58	23	42	21	10	31	25	33	28	78	2.32	−1.0	13	8,536	nw.	30	nw.	9	4	5	22	7.9	6.8	0.0
Royal Center	736	11	55	29.16	29.98		34.2		57	23	40	18	12	28	31				2.26	−0.7	11	8,486	nw.	43	e.	7	2	5	24	8.4	9.2	0.0
Terre Haute	575	96	129	29.35	29.98		38.2		59	23	45	22	10	32	26				2.51	−1.2	12	6,690	nw.	29	sw.	28	5	6	20	7.5	6.2	0.0
Cincinnati	627	11	51	29.28	29.98	−.07	38.0	−2.9	58	23	45	24	2	31	25	34	30	76	1.97	−1.9	13	5,667	ne.	27	sw.	24	2	4	25	8.5	8.1	0.0
Columbus	822	216	230	29.07	29.97	−.07	37.3	−1.8	56	23	43	22	11	31	20	34	30	79	1.34	−2.2	16	7,804	nw.	37	sw.	24	0	5	26	8.6	5.3	0.0
Dayton	899	137	173	28.99	29.97		37.1	−3.4	56	23	43	24	12	32	24	33	29	77	2.51	−1.2	16	6,317	nw.	33	sw.	28	2	5	24	8.2	4.5	0.0
Elkins	1,947	59	67	27.87	29.90	−.06	33.9	−6.1	52	23	40	19	10	28	29	31	28	84	2.93	−0.9	19	4,206	w.	26	se.	7	0	4	27	9.4	16.1	0.0
Parkersburg	637	77	82	29.31	29.98	−.06	38.8	−4.0	59	24	45	24	10	33	26	34	30	75	2.60	−0.9	19	4,142	nw.	24	sw.	24	0	2	29	9.1	5.6	0.0
Pittsburgh	842	353	410	29.04	29.96	−.08	36.4	−3.2	59	27	42	20	11	31	22	32	29	78	2.48	−0.6	16	7,161	w.	30	e.	7	1	7	23	8.5	3.9	0.0
Lower Lake Region							34.2	+1.2										77	2.19	−0.5										7.9		
Buffalo	767	247	280	29.09	29.94	−.08	32.5	+1.4	51	24	37	20	10	28	18	30	27	80	3.30	+0.7	16	8,973	w.	40	w.	29	2	6	23	8.2	19.0	0.0
Canton	448	10	61	29.44	29.93		31.8	+4.1	57	24	39	4	2	24	30				0.86	−1.6	11	5,333	e.	37	e.	8	2	12	17	7.4	4.8	0.0
Ithaca	836	74	100	29.00	29.93		35.2	+3.4	57	27	42	21	10	29	27				2.16	−0.2	11	6,313	nw.	34	se.	24	2	9	20	8.1	15.4	0.0
Oswego	335	71	85	29.56	29.89	−.12	34.5	+3.3	54	24	39	24	15	30	23	31	27	76	1.76	−0.8	15	6,646	n.	27	w.	12	0	10	21	8.3	11.9	0.0
Rochester	523	86	102	29.37	29.96	−.06	35.2	+3.2	57	24	40	21	14	30	22	32	28	76	3.61	+0.8	15	5,671	w.	24	w.	12	5	6	20	7.7	21.4	0.0
Syracuse	596	65	79	29.28	29.94	−.08	36.2	+4.8	57	24	41	24	15	31	24	31	26	74	1.98	−1.0	15	4,746	w.	24	e.	8	4	9	18	7.5	4.3	0.0
Erie	714	130	166	29.17	29.96	−.06	34.9	+0.4	54	27	38	21	10	30	20				2.00	−0.6	13	8,068	nw.	41	se.	28	4	6	21	7.7	11.8	0.0
Cleveland	762	267	337	29.11	29.95	−.08	33.9	−0.7	60	28	38	19	10	30	22	31	28	79	1.51	−1.2	15	8,829	w.	46	se.	7	3	6	22	8.4	4.1	0.0
Sandusky	629	5	67	29.27	29.97	−.06	35.0	−0.1	57	28	40	21	11	30	22	31	27	77	2.16	−0.6	15	6,072	e.	25	ne.	7	2	6	23	8.4	6.9	0.0
Toledo	628	208	243	29.29	29.99	−.04	34.6	−0.7	55	28	40	19	11	30	23	31	26	73	2.27	−0.3	11	8,091	n.	43	ne.	7	5	3	23	7.9	9.4	0.0
Fort Wayne	856	100	119	29.03	29.98		34.0	−4.9	55	23	39	19	12	29	22	31	28	80	1.96	−1.3	12	6,968	nw.	31	nw.	9	3	4	24	8.4	11.5	0.0
Detroit	730	218	258	29.17	29.99	−.04	34.0	+0.6	55	28	39	19	10	29	24	31	28	81	2.67	+0.3	13	6,658	nw.	36	sw.	28	0	6	19	7.2	14.3	0.0
Upper Lake Region							30.5	+2.2										80	2.33	+0.2										7.5		
Alpena	609	13	92	29.35	30.03	.00	28.2	+2.7	42	22	34	13	14	22	21	26	23	81	2.13	+0.1	13	7,556	nw.	32	ne.	28	5	9	17	7.0	17.2	T.
Escanaba	612	54	60	29.40	30.09	+.05	28.0	+3.8	43	22	34	7	7	22	21	25	22	79	1.25	−0.6	5	7,829	n.	36	n.	8	3	10	18	7.5	8.9	1.0
Grand Haven	632	54	89	29.30	30.01	−.02	32.1	+0.4	55	23	38	16	12	27	27	30	27	84	2.53	+0.1	11	7,060	n.	33	n.	9	4	3	24	8.4	13.7	0.0
Grand Rapids	707	70	244	29.22	30.01	−.02	33.6	+0.2	55	23	39	22	12	28	25	30	26	77	1.94	−0.5	10	7,868	n.	39	n.	9	2	5	24	8.6	11.5	0.0
Houghton	668	64	99	29.38	30.13	+.09	27.4	+4.6	50	23	33	2	7	22	29				1.61	−0.4	9	6,140	n.	33	n.	28	5	5	21	7.9	14.1	T.
Lansing	878	6	88	29.02	29.98		31.9	−0.8	57	28	38	14	10	26	27	30	28	88	2.10	−0.2	15	5,972	nw.	25	nw.	9	5	7	21	8.1	14.4	0.0
Ludington	637	60	66	29.31	30.02		31.5	+1.4	48	23	36	18	7	27	19	29	28	82	3.01	+0.7	13	6,359	n.	31	nw.	8	4	7	20	7.4	15.8	0.0
Marquette	734	77	111	29.28	30.11	+.07	29.3	+4.5	49	23	34	13	7	25	18	27	24	80	2.61	+0.4	13	6,965	nw.	29	nw.	9	3	5	24	8.5	26.0	6.0
Port Huron	638	70	120	29.29	29.97	−.06	31.5	+1.1	52	23	36	18	10	27	18	29	26	85	2.57	+0.5	12	7,242	n.	30	nw.	9	2	5	23	8.1	17.2	0.0
Sault Sainte Marie	614	11	52	29.36	30.08	+.05	27.0	+5.4	48	23	33	6	10	21	21	24	20	79	1.15	−0.7	12	5,465	nw.	29	n.	9	10	5	15	5.7	11.1	1.3
Chicago	673	7	131	29.27	30.02	−.01	34.8	−0.5	53	23	39	21	10	31	21	31	27	74	3.33	+0.8	12	7,815	ne.	31	ne.	7	4	7	20	7.6	19.8	
Green Bay	617	109	141	29.37	30.05	+.01	31.0	+2.4	52	23	37	13	1	25	21	28	24	79	1.71	−0.3	9	7,922	n.	38	ne.	28	4	5	22	8.2	14.9	6.5
Milwaukee	681	125	221	29.27	30.03	.00	33.7	+1.6	49	25	39	20	10	28	19	30	27	77	4.76	+2.3	13	9,226	n.	48	ne.	7	5	11	15	6.7	36.3	0.5
Duluth	1,133	5	47	28.89	30.16	+.10	27.5	+3.8	45	31	34	10	1	21	26	24	21	81	1.87	+0.3	10	8,649	ne.	32	ne.	26	10	6	15	6.0	13.5	0.0
North Dakota							26.1	+3.7										78	1.10	+0.3										6.5		
Moorhead	940	50	58	29.11	30.16	+.08	27.7	+5.0	48	20	37	2	15	18	29	24	20	75	0.81	−0.2	7	6,670	n.	24	n.	26	4	8	19	7.3	4.6	0.0
Bismarck	1,674	8	57	28.31	30.16	+.10	27.2	+3.0	50	21	36	−7	26	18	37	24	20	78	1.26	+0.4	6	6,009	n.	28	n.	26	9	9	13	6.1	4.4	0.0
Devils Lake	1,478	11	44	28.55	30.19	+.14	23.9	+4.1	47	22	33	−8	26	14	36	21	18	81	1.10	+0.3	10	7,167	ne.	37	ne.	25	7	9	15	6.6	3.3	T.
Ellendale	1,457	10	56	28.54	30.16		26.5		54	22	36	2	26	17	33				1.27	+0.4	6	9,934	ne.	41	ne.	26	7	7	17	6.9	4.3	T.
Grand Forks	833	12	67				26.0		47	31	35	0	27	17	27	22			1.04		9		nw.	37	e.	13	15	9	7		3.4	0.0
Williston	1,878	41	48	28.12	30.17	+.13	25.7	+2.8	60	31	36	−7	26	15	43	23	19	77	1.06	+0.4	6	5,033	se.	31	ne.	25	9	10	12	5.5	10.9	0.0
Upper Mississippi Valley							35.8	−0.3										72	2.20	−0.1										6.9		
Minneapolis	918	102	208	29.08	30.09		31.4	+1.8	51	25	38	12	1	25	27				1.49	+0.1	7	7,678	n.	32	n.	24	6	6	19	7.2	0.4	0.0
St. Paul	837	236	261	29.17	30.11	+.06	31.6	+2.5	49	12	38	12	1	25	26				1.56	+0.1	10	7,562	nw.	31	nw.	28	7	8	16	6.9	2.4	0.0
La Crosse	714	11	48	29.27	30.06	+.02	33.2	+1.7	54	12	40	13	1	26	30	29	24	74	1.79	+0.2	9	3,552	nw.	18	nw.	8	7	3	21	7.2	14.8	1.0
Madison	974	70	78	28.96	30.05	+.01	31.7	+1.1	53	23	38	15	1	26	22	28	24	77	2.35	+0.3	10	6,899	nw.	42	n.	28	7	6	18	7.1	21.0	3.0
Wausau	1,247	4	62		30.10		30.4		52	12	37	6	1	23	28				1.33	−0.4	9	4,812	n.	23	n.	28	10	6	15		10.8	T.
Charles City	1,015	10	51	28.97	30.09	+.04	33.8	+3.1	54	25	42	15	4	26	34	29	23	71	1.43	−0.3	4	4,962	se.	24	nw.	8	12	4	15	5.8	7.7	0.0
Davenport	606	71	79	29.35	30.03	.00	36.2	+0.1	56	22	43	20	4	29	24	31	26	70	2.87	+0.6	11	7,519	nw.	36	ne.	7	8	5	18	7.1	10.6	T.
Des Moines	861	5	99	29.13	30.06	+.02	36.0	+0.1	59	13	44	17	16	28	29	31	24	66	1.52	−0.3	8	7,420	nw.	33	n.	7	4	12	15	7.0	6.9	T.
Dubuque	700	81	96	29.28	30.05	+.01	34.4	+0.4	54	21	41	20	4	28	27	30	26	74	2.20	+0.2	9	5,005	n.	25	ne.	7	7	7	17	6.8	18.1	3.4
Keokuk	614	64	78	29.35	30.04	+.01	36.7	−2.2	58	22	44	21	4	30	26	32	26	70	2.18	−0.2	9	5,681	nw.	27	nw.	24	8	7	16	6.5	15.9	0.0
Cairo	358	87	93	29.60	29.99	−.05	43.4	−3.8	66	13	51	27	10	36	25	38	32	67	4.20	+0.4	8	7,121	n.	38	sw.	7	5	6	20	7.5	0.5	0.0
Peoria	609	11	45	29.34	30.02	−.01	36.7	−0.3	57	22	44	18	11	30	26	32	29	78	2.50	−0.2	10	5,480	nw.	26	ne.	7	8	7	16	6.3	10.3	0.0
Springfield, Ill	636	5	191	29.30	29.99	−.04	37.8	−2.4	59	13	45	24	4	31	23	34	30	77	2.79	−0.4	10	9,222	nw.	46	ne.	7	5	9	17	7.2	15.1	0.0
Hannibal	534	74	109	29.42	30.01	−.01	37.6	−3.4	61	13	44	23	10	31	30				2.36	−0.2	12	6,474	nw.	28	ne.	7	7	7	17	6.8	10.8	0.0
St. Louis	568	265	303	29.37	29.99	−.04	40.6	−3.2	68	13	47	26	8	34	28	35	29	69	2.39	−1.0	9	8,682	nw.	40	nw.	24	7	10	14	6.2	2.7	0.0
Missouri Valley							36.4	−1.1										69	1.83	0.0										6.2		
Columbia, Mo	784	6	84	29.15	30.01	−.02	38.4	−4.2	61	17	45	19	10	32	32				2.97	0.0	11	6,521	nw.	29	nw.	24	7	5	19	6.8	11.5	0.0
Kansas City	963	161	181	28.98	30.04	+.02	39.2	−3.5	66	17	46	23	9	32	32	34	28	70	2.35	−0.2	11	8,571	nw.	40	w.	24	10	7	14	5.8	14.1	0.0
St. Joseph	967	11	49	28.98	30.04		38.0		65	17	46	20	9	30	33	32	26	70	2.44	+0.4	10	7,148	nw.	38	nw.	24	13	4	14	5.5	12.5	T.
Springfield, Mo	1,324	98	104	28.57	30.00	−.02	40.8	−4.4	62	17	49	23	9	33	28	35	29	68	2.54	−0.8	11	8,087	nw.	31	w.	24	17	5	9	4.5	6.8	0.0
Iola	984	11	50	28.95	30.03	+.02	40.8	−3.7	68	17	50	19	28	32	34				2.56	−0.1	8	5,523	n.	24	nw.	23	9	7	15	6.3	6.5	0.0
Topeka	987	92	107				39.4	−3.2	70	17	48	20	9	31	34				1.94	−0.2	9	7,698	nw.	33	nw.	24	10	8	13	5.7	10.4	0.0
Lincoln	1,189	11	81	28.77	30.07	+.05	36.4	−1.1	60	22	45	14	9	28	34	32	26	72	1.39	+0.1	10	7,630	n.	38	w.	23	5	11	15	6.8	8.5	0.0
Omaha	1,105	115	122	28.86	30.08	+.04	36.4	−0.6	56	22	44	20	9	29	28	31	24	64	1.15	−0.2	10	6,742	nw.	32	nw.	24	11	6	14	6.0	8.9	0.0
Valentine	2,598	47	54	27.33	30.18	+.15	31.8	−0.5	68	22	42	−1	27	21	36	26	22	77	1.84	+0.8	9	6,144	n.	39	nw.	23	4	10	17	7.2	13.8	T.
Sioux City	1,135	94	164	28.84	30.09	+.04	35.2	+2.5	57	12	44	16	29	26	32	30	23	65	0.67	−0.5	7	8,875	nw.	38	nw.	24	6	10	15	6.8	3.0	0.0
Huron	1,306	59	74	28.70	30.14	+.08	31.9	+3.0	60	20	43	7	28	21	37	27	21	67	0.54	−0.4	9	6,840	n.	30	n.	23	9	12	10	6.8	5.0	0.0
Pierre	1,572	70	75	28.41	30.13	+.08	32.6	+1.1	64	22	43	3	27	22	35	27	22	69	2.22	+1.4	10	6,436	nw.	37	nw.	23	6	13	12	6.2	18.9	T.
Yankton	1,233	49	57	28.77	30.13	+.08	34.4	+1.2	59	17	44	12	28	25	35				1.14	−0.1	6	6,022	nw.	29	nw.	23	6	9	16	6.5	7.0	T.

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1931*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with .01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern Slope							32.5	+1.2										67	1.01	0.0										6.4		
Billings	3,140	5	----				36.0	----	74	21	52	0	27	20	54	----	----	----	0.60	----	9	----	nw.	----	----	----	4	11	16	----	2.5	0.0
Havre	2,505	11	67	27.41	30.12	+0.12	31.6	+4.5	62	21	43	−4	26	20	35	27	22	71	0.82	+0.3	10	6,247	sw.	27	w.	3	2	18	11	6.5	9.4	0.0
Helena	4,124	89	113	25.82	30.10	+.09	35.8	+3.4	65	15	46	−5	27	26	37	28	18	51	0.32	−0.5	8	5,889	sw.	30	w.	4	0	13	18	7.8	2.0	0.0
Kalispell	2,973	48	56	26.98	30.10	+.11	35.7	+2.8	59	21	44	5	26	28	30	32	27	75	0.93	0.0	15	3,565	nw.	27	w.	3	4	6	21	7.4	4.7	0.0
Miles City	2,371	48	55	27.54	30.16	+.14	34.0	+5.4	65	15	45	0	26	23	44	29	23	67	0.34	−0.5	9	4,895	s.	30	nw.	19	7	11	13	6.2	1.4	0.0
Rapid City	3,259	50	58	26.64	30.16	+.15	31.4	−1.2	62	16	42	−5	26	21	51	27	21	71	1.15	+0.2	11	6,134	n.	38	nw.	23	8	11	12	6.1	7.9	2.1
Cheyenne	6,088	84	101	23.96	30.09	+.13	29.8	−3.3	56	16	40	−8	27	20	38	25	18	63	1.16	+0.1	13	10,669	w.	46	w.	22	10	5	16	6.2	15.7	T.
Lander	5,372	60	68	24.64	30.10	+.11	33.1	+0.7	67	21	46	−7	27	20	38	26	18	60	0.85	−0.3	5	3,852	sw.	39	sw.	9	13	13	5	4.5	8.5	0.1
Sheridan	3,790	10	47	26.13	30.13	----	32.2	----	67	21	44	−3	27	20	40	27	21	68	1.88	+0.7	11	3,534	nw.	32	nw.	19	7	8	16	6.5	5.9	0.0
Yellowstone Park	6,241	11	48	----	30.17	+.15	26.8	+0.3	53	21	36	−4	6	17	32	----	----	68	0.80	−0.9	13	6,320	sw.	30	nw.	25	2	8	21	----	11.3	0.0
North Platte	2,821	11	51	27.00	30.09	+.09	34.6	−2.0	69	16	46	0	26	23	40	29	24	74	1.81	+1.0	8	5,488	n.	34	nw.	23	7	12	12	6.4	13.2	2.5
Middle Slope							39.3	−4.0										65	1.84	+0.2										5.7		
Denver	5,292	106	113	24.71	30.07	+.12	36.6	−2.7	68	22	47	−2	27	26	36	29	20	56	1.00	0.0	14	5,535	s.	38	nw.	26	5	15	11	6.2	19.0	0.0
Pueblo	4,685	80	86	25.28	30.04	+.12	38.2	−3.4	72	22	51	10	27	25	45	31	21	55	0.41	−0.2	8	4,688	nw.	38	w.	22	13	12	6	4.9	2.4	0.0
Concordia	1,392	50	58	28.58	30.10	+.09	37.0	−4.0	62	12	47	14	28	28	37	32	28	74	1.38	+0.2	10	6,395	nw.	38	nw.	23	10	7	14	6.0	7.6	T.
Dodge City	2,509	11	51	27.43	30.10	+.13	37.9	−4.9	73	12	50	6	27	26	41	32	27	73	2.83	+1.9	10	7,267	nw.	27	nw.	5	12	7	12	5.4	12.1	1.0
Wichita	1,358	139	158	28.56	30.03	+.04	41.1	−4.0	70	12	50	14	28	32	36	36	30	69	2.52	+0.8	8	8,585	n.	38	sw.	12	11	5	15	5.9	5.0	0.0
Broken Arrow	765	11	56	29.18	30.01	----	44.5	----	69	18	54	19	28	35	33	----	----	----	1.65	−2.2	8	10,535	nw.	42	nw.	7	7	9	15	6.4	1.5	0.0
Oklahoma City	1,214	10	47	28.72	30.02	+.04	45.0	−5.0	76	12	55	16	28	35	36	38	30	64	3.06	+1.1	9	8,064	n.	28	nw.	7	14	7	10	5.3	2.2	0.0
Southern Slope							49.2	−5.4										58	0.96	+0.1										4.2		
Abilene	1,738	10	52	28.20	30.03	+.07	49.9	−6.6	80	22	63	19	27	37	38	41	33	60	1.12	−0.2	8	7,758	s.	31	s.	12	11	10	10	5.0	0.4	0.0
Amarillo	3,676	10	49	26.26	30.04	+.09	42.0	−4.9	80	22	54	7	27	30	41	34	26	61	1.69	+1.0	7	7,282	nw.	27	se.	25	13	8	10	4.7	15.0	0.0
Del Rio	944	64	71	28.99	29.99	+.04	57.2	−6.3	87	23	70	30	9	45	38	49	42	63	0.66	−0.1	3	6,633	se.	37	n.	30	16	12	3	3.4	0.0	0.0
Roswell	3,566	75	85	26.36	29.99	+.09	47.5	−3.8	85	22	64	16	27	32	51	37	24	47	0.38	−0.4	4	5,621	s.	42	nw.	19	17	10	4	3.6	1.6	0.0
Southern Plateau							51.9	+1.2										40	0.33	−0.2										2.6		
El Paso	3,778	152	175	26.17	29.96	+.08	54.6	−1.2	82	22	67	28	7	42	39	40	21	33	0.38	0.0	3	7,226	w.	44	w.	25	22	8	1	2.2	0.0	0.0
Santa Fe	7,013	38	53	23.19	29.99	+.10	36.2	−3.5	67	22	48	6	27	25	32	28	17	50	1.18	+0.4	9	4,513	n.	29	ne.	19	15	8	8	4.3	12.2	0.0
Flagstaff	6,907	10	59	23.32	29.94	+.03	38.6	+2.7	68	21	54	11	9	23	45	31	----	57	0.25	----	1	6,151	nw.	28	ne.	30	13	18	0	----	T.	0.0
Phoenix	1,108	10	107	28.80	29.95	+.04	62.8	+2.1	91	22	78	34	7	48	37	47	28	31	0.07	−0.6	1	3,732	e.	24	sw.	25	22	6	3	2.3	0.0	0.0
Yuma	141	9	54	29.83	29.98	+.04	66.4	+2.3	97	22	82	36	7	50	42	50	30	31	0.00	−0.3	0	4,231	n.	26	nw.	25	25	4	2	1.5	0.0	0.0
Independence	3,957	6	27	26.02	30.06	+.12	53.0	+4.5	81	31	69	24	6	37	42	38	----	----	T.	−0.5	0	----	nw.	----	----	----	22	8	1	----	0.0	0.0
Middle Plateau							41.1	+0.2										48	0.54	−0.5										4.7		
Reno	4,532	74	81	25.53	30.10	+.12	44.2	+3.2	72	20	58	16	6	30	42	36	25	50	0.08	−0.7	3	4,080	w.	35	se.	11	15	12	4	4.0	0.0	0.0
Tonopah	6,090	12	20	----	----	----	42.6	----	70	21	53	16	6	32	29	33	23	49	0.16	----	4	----	nw.	----	----	----	----	----	----	----	----	----
Winnemucca	4,344	18	56	25.70	30.13	+.12	40.8	+0.8	71	31	56	8	6	26	44	33	20	48	0.25	−0.7	5	5,237	sw.	27	nw.	24	12	9	10	4.9	T.	0.0
Modena	5,473	10	43	24.64	30.03	+.07	38.9	+0.7	72	21	54	10	27	23	42	30	17	46	0.59	−0.4	3	6,795	w.	34	nw.	18	13	11	7	4.4	4.8	0.0
Salt Lake City	4,360	163	203	25.68	30.11	+.13	41.4	−0.3	70	21	50	19	27	32	28	34	24	52	1.14	−0.8	7	4,842	nw.	30	nw.	22	11	10	10	5.3	8.7	0.0
Grand Junction	4,602	60	68	25.39	30.01	+.07	40.2	−3.4	67	22	53	16	27	28	38	32	19	46	0.63	−0.1	6	3,600	nw.	26	w.	22	11	11	9	4.8	2.5	0.0
Northern Plateau							42.4	+0.6										63	2.23	+1.1										6.8		
Baker	3,471	46	53	26.53	30.17	+.14	38.4	+0.8	60	20	48	19	6	29	28	34	30	75	1.93	+0.8	14	4,129	se.	21	nw.	25	6	6	19	6.7	4.5	0.0
Boise	2,739	79	87	27.27	30.17	+.14	43.4	+0.7	65	15	53	23	7	34	31	37	28	56	2.49	+1.1	12	4,201	se.	21	se.	8	8	6	17	6.5	1.3	0.0
Lewiston	757	40	48	29.32	30.15	+.12	45.7	+0.3	66	20	55	25	7	36	34	----	----	----	4.07	+2.9	16	2,623	e.	26	nw.	3	5	8	18	7.0	0.1	0.0
Pocatello	4,477	60	68	25.54	30.14	+.13	36.5	−0.9	65	21	46	12	1	26	34	31	23	60	0.81	−0.5	9	6,120	se.	34	sw.	22	5	16	10	5.8	5.6	0.0
Spokane	1,929	101	110	28.04	30.12	+.11	41.6	+1.9	58	21	49	21	26	34	27	37	31	70	1.52	+0.3	14	4,770	s.	21	sw.	18	7	5	19	7.3	0.5	0.0
Walla Walla	991	57	65	29.04	30.12	+.10	46.6	+0.5	64	1	55	25	27	39	27	41	34	63	3.70	+2.1	15	3,448	s.	22	w.	18	5	9	17	7.2	3.0	0.0
Yakima	1,076	58	67	28.95	30.11	----	44.8	+0.7	66	21	55	23	6	35	32	38	28	56	1.11	+0.7	7	3,334	nw.	25	nw.	3	5	8	18	6.9	T.	0.0
North Pacific Coast Region							47.5	+2.3										76	5.40	+1.5										7.4		
North Head	211	11	56	29.88	30.12	+.11	47.3	+2.1	62	2	52	36	27	43	17	45	42	83	9.11	+3.6	23	12,856	s.	60	s.	19	5	11	15	6.8	T.	0.0
Port Angeles	29	8	53	----	30.08	----	44.5	----	59	19	51	32	6	38	18	----	----	----	1.74	−0.5	17	4,016	s.	30	w.	24	3	11	17	----	0.0	0.0
Seattle	125	215	250	29.96	30.09	+.10	47.1	+2.2	67	2	53	32	5	41	23	43	38	74	4.37	+1.3	21	6,970	s.	43	sw.	21	3	11	17	7.3	T.	0.0
Tacoma	194	172	201	29.88	30.10	+.10	46.6	+2.4	67	2	53	29	5	40	23	----	----	----	5.41	+1.9	21	5,738	s.	33	sw.	21	3	8	20	7.5	T.	0.0
Tatoosh Island	86	9	53	29.96	30.06	+.10	46.2	+3.3	55	7	50	34	28	43	12	44	41	84	9.73	+1.9	24	12,219	e.	51	e.	27	4	6	21	7.6	T.	0.0
Medford	1,329	29	58	28.72	30.14	----	48.0	----	71	2	60	22	5	36	41	43	36	69	1.16	−0.5	16	----	nw.	30	n.	3	7	8	16	6.8	0.0	0.0
Portland, Oreg.	153	68	106	29.97	30.13	+.11	48.8	+1.9	65	2	56	33	5	42	26	43	40	74	8.12	+4.2	20	4,375	sw.	26	w.	21	3	1	27	8.5	T.	0.0
Roseburg	510	75	99	29.61	30.16	+.12	48.8	+1.7	71	2	58	28	6	40	38	45	40	74	3.58	+0.3	18	2,787	s.	21	sw.	31	4	7	20	7.3	0.0	0.0
Middle Pacific Coast Region							56.5	+3.7										68	1.42	−2.0										4.6		
Eureka	62	73	89	30.12	30.19	+.13	51.1	+2.8	66	6	57	36	5	45	26	48	45	81	3.35	−1.9	14	5,054	se.	31	n.	4	8	8	15	6.2	0.0	0.0
Red Bluff	330	5	58	29.75	30.11	+.07	58.0	+4.4	82	2	70	36	6	46	37	48	38	53	0.38	−2.9	7	4,648	nw.	24	se.	11	9	14	8	5.1	0.0	0.0
Sacramento	69	106	117	30.04	30.11	+.08	57.7	+3.4	79	31	69	38	7	47	32	52	46	69	1.14	−1.4	6	4,951	s.	24	nw.	26	20	8	3	2.8	0.0	0.0
San Francisco	155	208	243	29.96	30.13	+.07	59.0	+4.8	76	2	66	48	29	52	23	51	45	67	1.68	−1.5	7	4,412	w.	25	nw.	28	9	15	7	4.9	0.0	0.0
San Jose	141	12	110	29.98	30.13	----	56.6	+2.9	78	23	69	37	29	44	35	----	----	----	0.54	−2.1	4	3,909	nw.	23	nw.	25	11	16	4	4.2	0.0	0.0
South Pacific Coast Region							62.2	+5.8										56	0.18	−1.9										3.3		
Fresno	327	89	98	29.74	30.10	+.09	58.6	+3.6	81	21	71	40	26	46	31	50	41	60	0.48	−1.1	3	4,381	nw.	23	nw.	25	18	10	3	3.7	0.0	0.0
Los Angeles	338	159	191	29.67	30.03	+.01	66.0	+8.5	93	21	76	49	7	56	28	52	39	45	T.	−2.8	0	3,713	ne.	22	nw.	25	19	9	3	2.6	0.0	0.0
San Diego	87	62	70	29.93	30.02	.00	61.9	+5.2	90	21	71	45	7	53	31	53	47	64	0.06	−1.7	2	3,768	nw.	20	w.	24	19	6	6	3.7	0.0	0.0
West Indies																																
San Juan, P. R.	82	9	54	29.88	29.97	----	78.2	+2.8	91	18	84	69	9	72	19	----	----	----	2.54	−0.6	9	6,462	e.	27	e.	14	6	21	4	5.2	0.0	0.0
Panama Canal																																
Balboa Heights	118	6	97	----	29.84	----	82.8	+1.6	94	25	91	72	11	75	20	----	----	[1] 76	0.70	0.0	----	6,968	n.	26	n.	13	2	21	8	6.3	0.0	0.0
Cristobal	36	6	97	----	29.86	----	82.7	+1.2	88	29	86	75	9	79	11	76	74	[1] 77	4.48	+2.9	----	9,523	n.	28	nw.	3	2	17	12	6.6	0.0	0.0
Alaska																																
Fairbanks	455	11	44	[2] 29.52	[2] 30.07	----	8.0	----	46	28	22	−28	14	−6	42	9	0	58	0.15	----	2	2,157	n.	20	ne.	12	19	2	10	3.8	2.1	5.8
Juneau	80	11	50	[2] 29.87	[2] 29.96	----	32.8	----	52	27	38	9	13	28	21	30	23	67	3.36	----	18	5,152	s.	38	e.	8	7	7	17	6.6	4.2	0.0
Hawaiian Islands																																
Honolulu	38	86	100	[2] 30.02	[2] 30.06	----	72.4	+1.0	80	29	77	63	1	68	13	66	62	72	0.94	−2.3	9	5,001	e.	26	ne.	31	13	14	4	4.2	0.0	0.0

[1] Observations taken bihourly.

[2] Pressure not reduced to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meterological Service, March, 1931*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Station, departure from normal	Mean max.+mean min.÷2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	*Inches*	*Inches*	*Inches*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*Inches*	*Inches*	*Inches*
Cape Race, N. F	99				31.8		36.9	26.7	43	18	2.57		4.3
Sydney, C. B. I	48	29.87	29.92	+0.04	32.3	+6.1	37.4	27.3	52	16	5.66	+0.73	44.0
Halifax, N. S	88	29.76	29.87	−.07	34.7	+5.7	39.6	29.8	50	25	4.09	−1.37	13.9
Yarmouth, N. S	65	29.73	29.80	−.15	35.7	+4.9	41.5	29.9	56	23	4.24	−0.76	19.0
Charlottetown, P. E. I	38	29.82	29.86	−.04	31.5	+6.1	36.0	27.0	45	14	2.64	−0.57	23.2
Chatham, N. B	28	29.86	29.89	−.01	31.1	+8.1	38.8	23.5	52	5	2.12	−1.35	13.8
Father Point, Que	20	29.95	29.97	+.07	30.0	+9.7	39.8	20.3	54	−14	0.24	−2.49	1.1
Quebec, Que	296	29.64	29.98	+.02	31.5	+10.3	36.5	26.5	44	6	1.80	−1.46	16.9
Doucet, Que	1,236				22.5		33.2	11.9	52	−12	0.86		8.5
Montreal, Que	187	29.72	29.94	−.06	33.9	+10.1	39.1	28.7	51	14	1.62	−2.17	8.4
Ottawa, Ont	236	29.68	29.96	−.05	34.0	+12.5	42.1	25.9	55	8	1.46	−1.26	7.5
Kingston, Ont	285	29.62	29.94	−.07	34.2	+8.6	40.1	28.3	52	14	1.72	−0.92	8.4
Toronto, Ont	379	29.54	29.97	−.05	33.4	+6.1	38.8	28.1	48	19	2.81	+0.17	17.2
Cochrane, Ont	930				19.0		27.6	10.5	49	−9	1.21		12.1
White River, Ont	1,244	28.75	30.12	+.09	18.6	+6.4	29.6	7.7	47	−20	0.84	−0.54	7.4
London, Ont	808				32.3		38.6	26.0	51	17	2.16		14.0
Southampton, Ont	656	29.25	29.98	−.05	29.4	+4.7	35.5	23.3	46	11	2.62	−0.03	19.9
Parry Sound, Ont	688	29.26	29.97	−.05	28.5	+7.4	35.4	21.7	46	8	3.02	+0.79	20.1
Port Arthur, Ont	644	29.44	30.18	+.13	25.3	+8.5	32.6	18.1	40	4	0.30	−0.67	2.8
Winnipeg, Man	760	29.38	30.26	+.17	19.9	+7.6	27.8	12.0	42	−9	0.89	−0.14	7.0
Minnedosa, Man	1,690	28.33	30.23	+.17	18.5	+6.0	29.5	7.5	44	−15	0.82	+0.17	8.2
Le Pas, Man	860				12.5		24.0	1.0	43	−29	1.17		11.7
Qu'Appelle, Sask	2,115	27.82	30.16	+.12	20.7	+5.8	30.1	11.2	57	−19	1.02	+0.25	9.8
Moose Jaw, Sask	1,759				24.0		34.9	13.1	63	−15	0.98		8.6
Swift Current, Sask	2,392	27.47	30.08	+.06	27.4	+5.4	38.5	16.2	63	−14	0.66	−0.15	4.9
Medicine Hat, Alb	2,144												
Calgary, Alb	3,428												
Banff, Alb	4,521												
Prince Albert, Sask	1,450	28.60	30.25	+.17	18.5	+6.5	28.4	8.6	52	−27	0.88	+0.11	8.8
Battleford, Sask	1,592	28.38	30.21	+.15	21.1	+8.0	31.5	10.6	60	−28	0.25	−0.21	2.5
Edmonton, Alb	2,150												
Kamloops, B. C	1,262												
Victoria, B. C	230	29.81	30.07	+.10	45.4	+3.5	50.3	40.5	57	34	2.40	−0.72	T.
Barkerville, B. C	4,180												
Estevan Point, B. C	20												
Prince Rupert, B. C	170												
Hamilton, Ber	151												

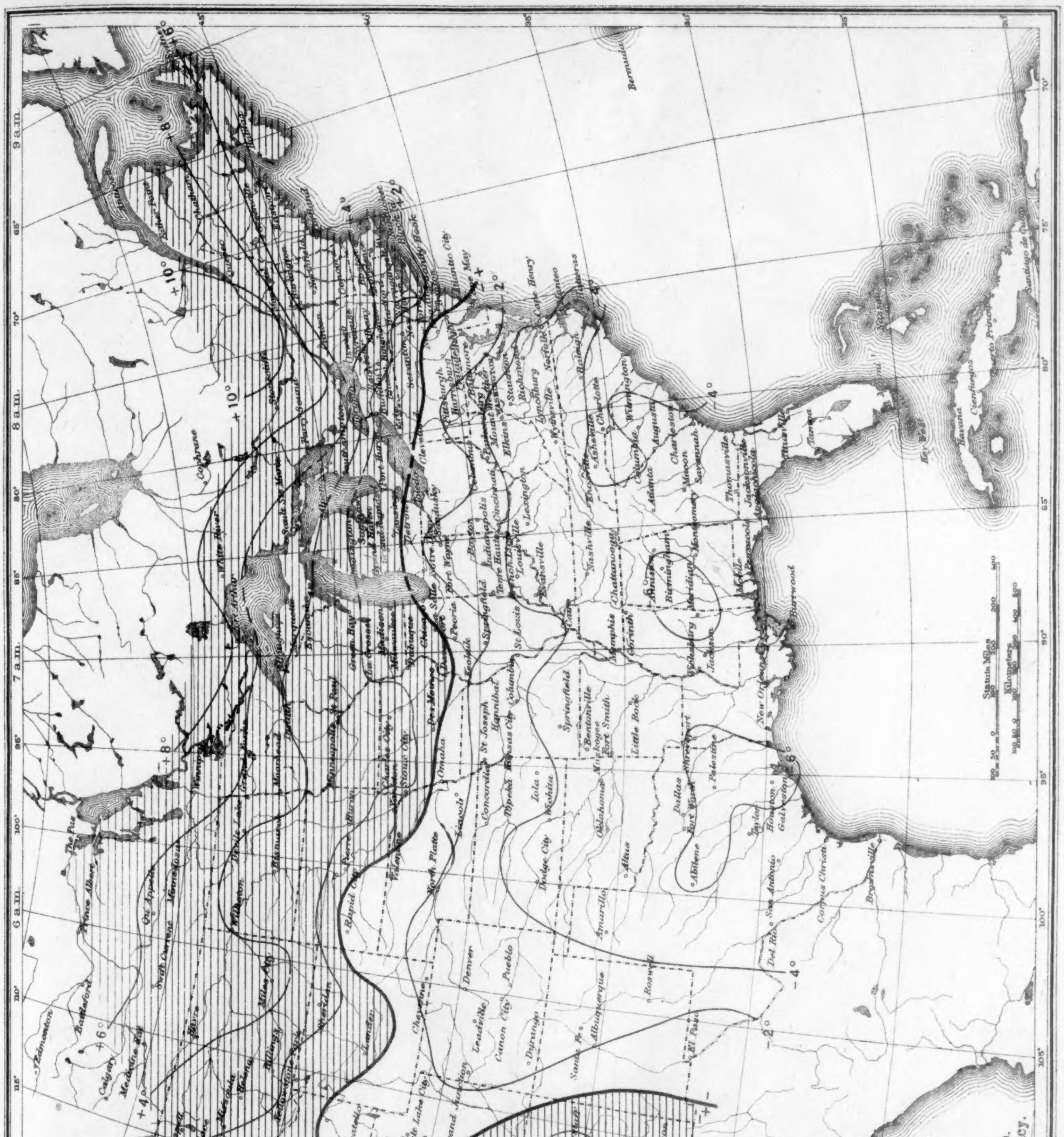
LATE REPORTS, FEBRUARY, 1931

Medicine Hat, Alb	2,144	27.46	29.75	−.30	34.8	+23.6	46.7	23.0	59	10	0.00	−0.67	0.0
Banff, Alb	4,521	25.30	30.01	+.03	25.9	+6.7	36.4	15.4	42	−5	0.45	−0.47	3.5
Edmonton, Alb	2,150	27.54	29.86	−.16	31.7	+23.4	40.9	22.6	50	6	T.	−0.67	T.
Kamloops, B. C	1,262	28.75	30.08	+.12	33.3	+5.0	37.8	28.7	52	13	0.43	−0.36	3.7
Esteven Point, B. C	20				42.3		48.4	36.2	53	29	12.21		0.0
Prince Rupert, B. C	170				39.7		43.6	35.9	47	32	8.80		T.

56409—31——4

Chart I. Departure (°F.) of the Mean Temperature from the Normal, March, 1931

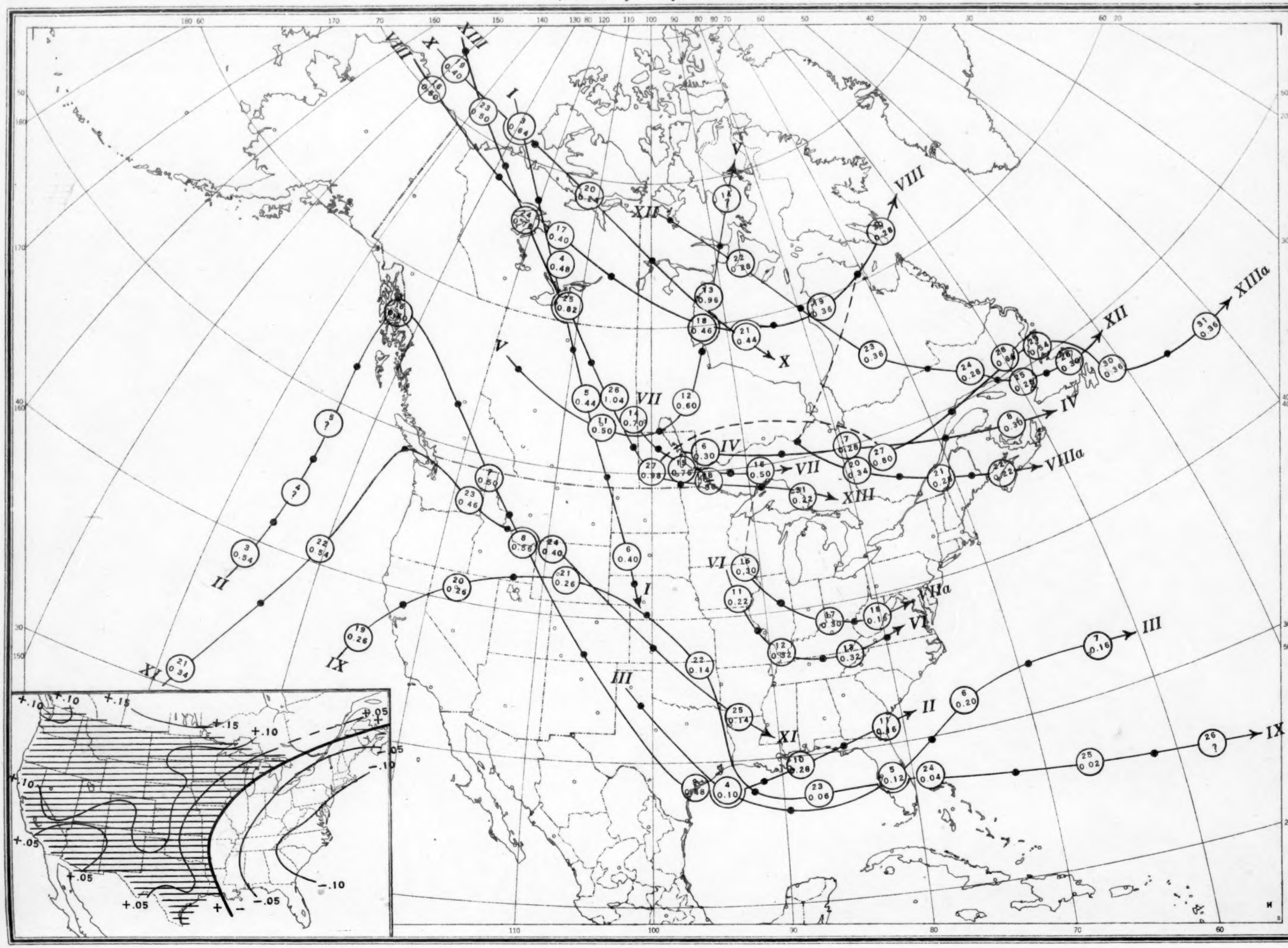
Chart I. Departure (°F.) of the Mean Temperature from the Normal, March, 1931



Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.

Chart II. Tracks of Centers of Anticyclones, March, 1931. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by Welby R. Stevens)



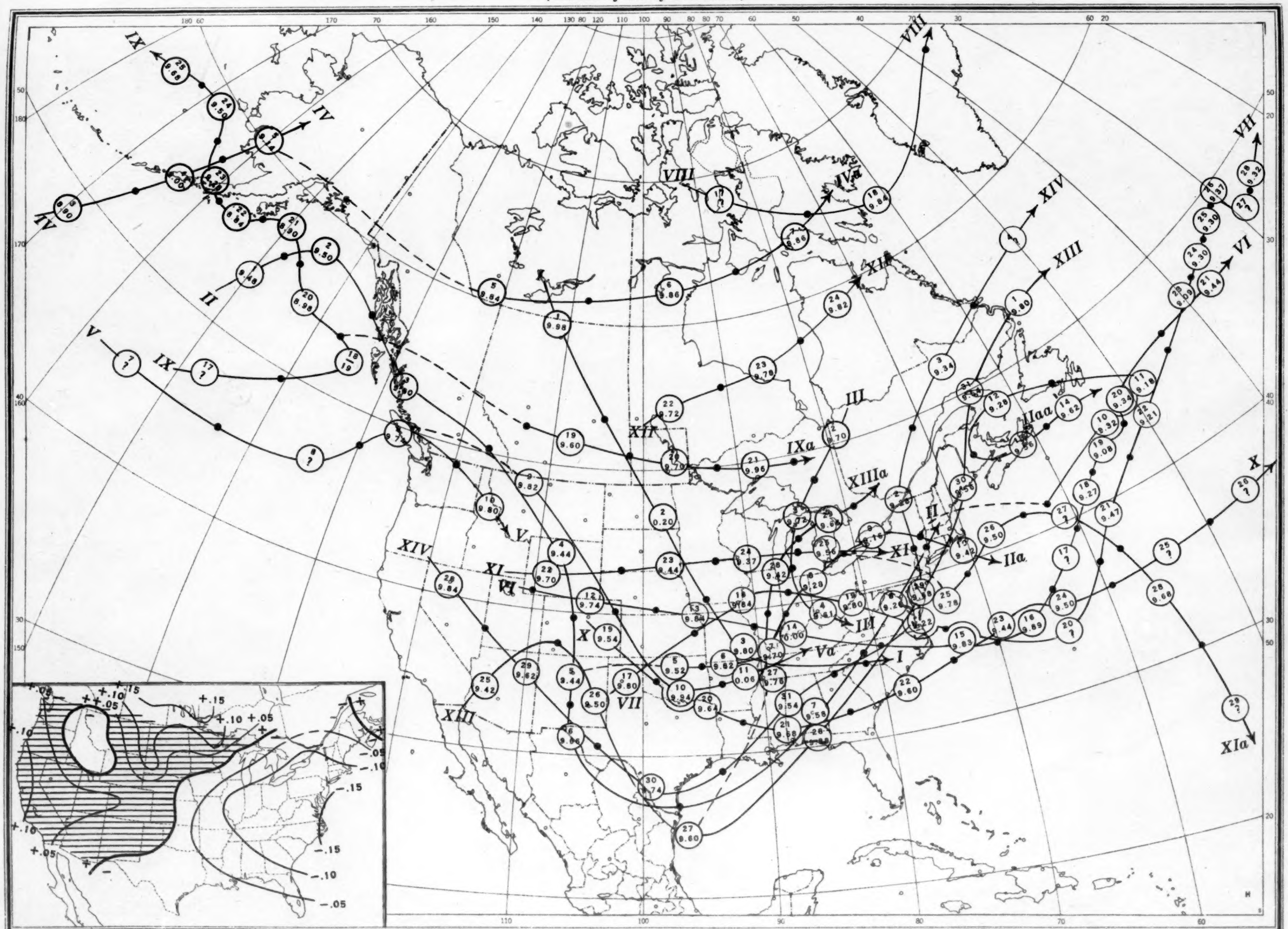
Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, March, 1931. (Inset) Change in Mean Pressure from Preceding Month

Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, March, 1931. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by Welby R. Stevens)



Circle indicates position of cyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 8 p. m. (75th meridian time)

Chart IV. Percentage of Clear Sky between Sunrise and Sunset, March, 1931

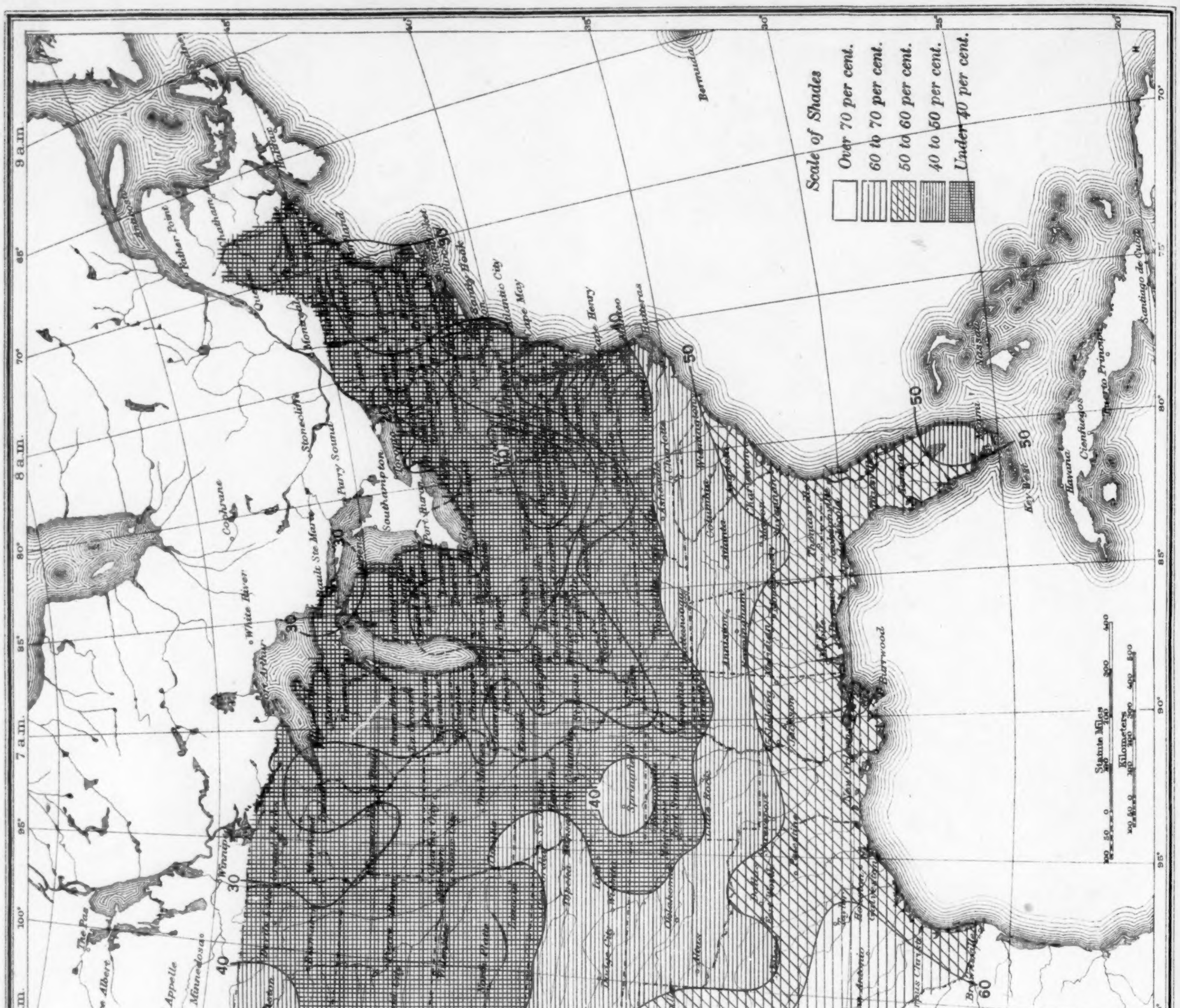


Chart V. Total Precipitation, Inches, March, 1931. (Inset) Departure of Precipitation from Normal

Chart V. Total Precipitation, Inches, March, 1931. (Inset) Departure of Precipitation from Normal

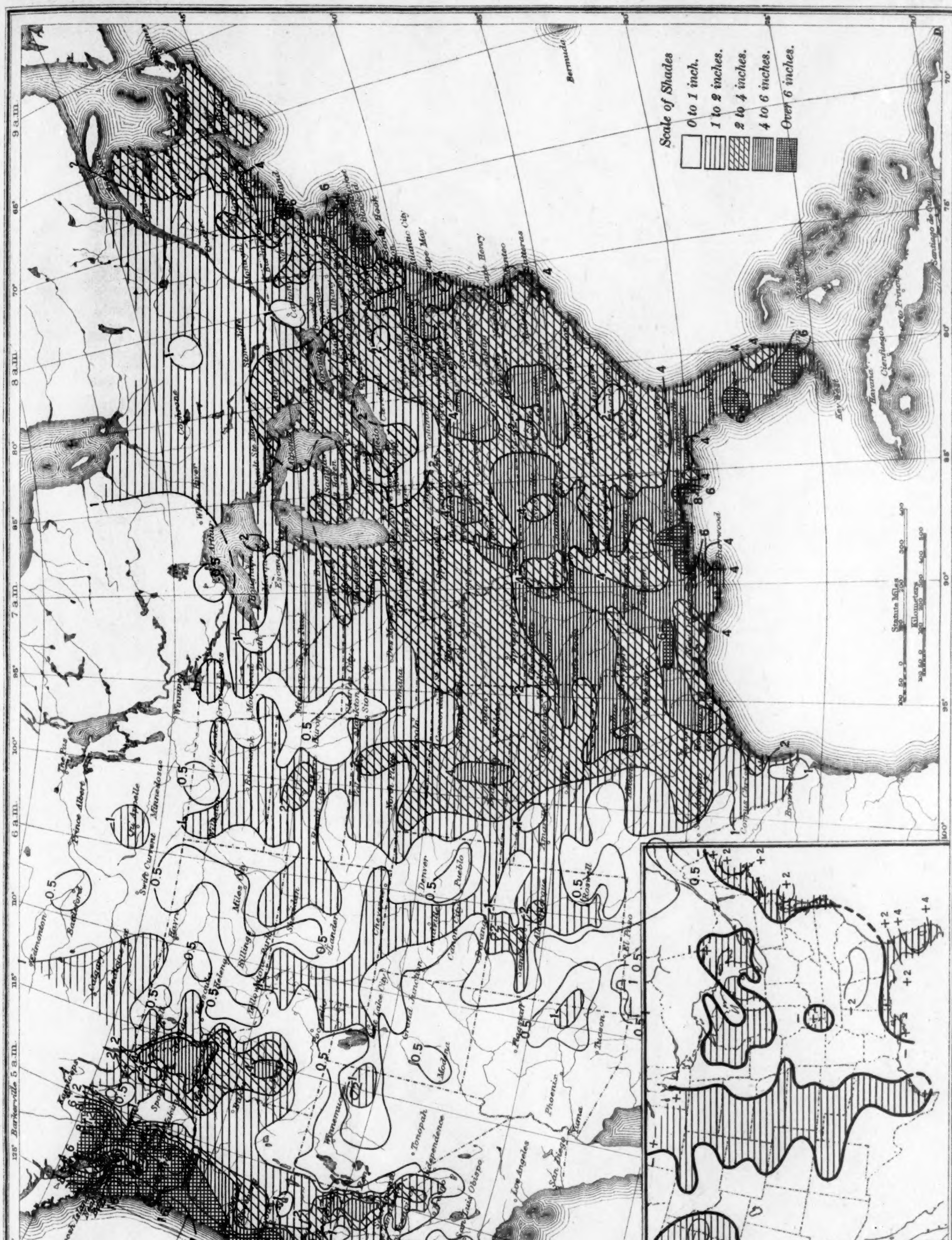


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, March, 1931

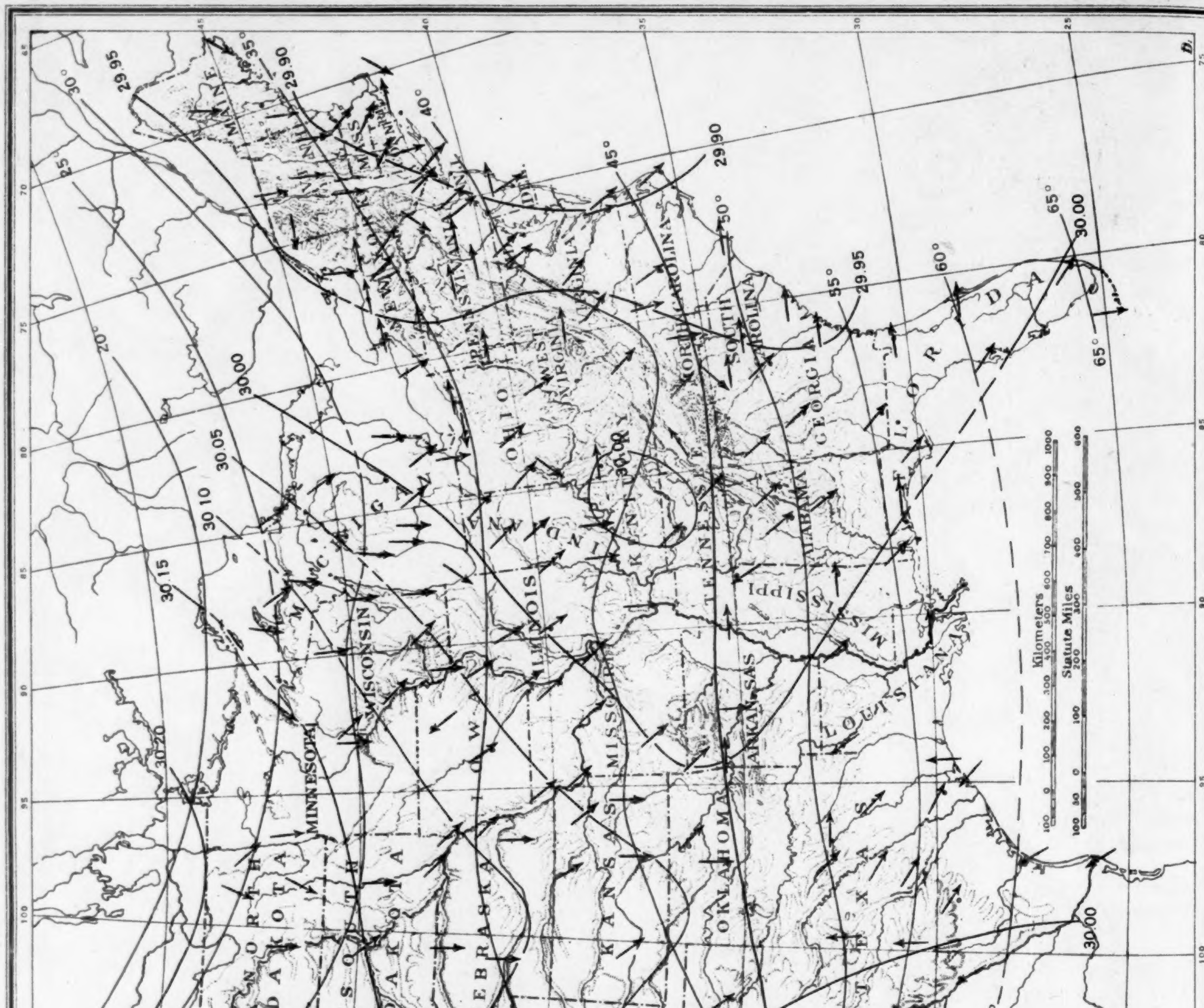


Chart VII. Total Snowfall, Inches, March, 1931. (Inset) Depth of Snow on Ground at end of Month

Chart VII. Total Snowfall, Inches, March, 1931. (Inset) Depth of Snow on Ground at end of Month

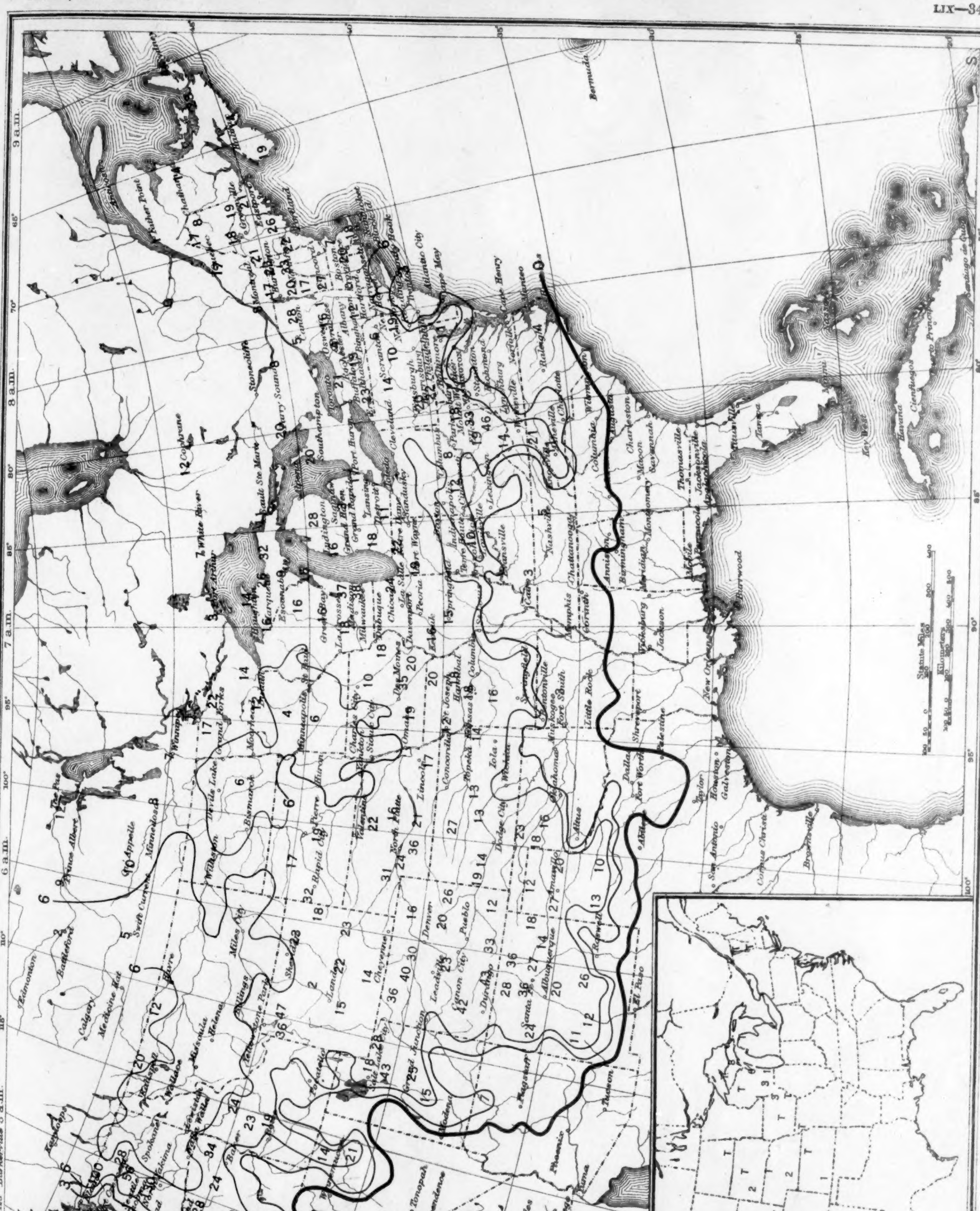
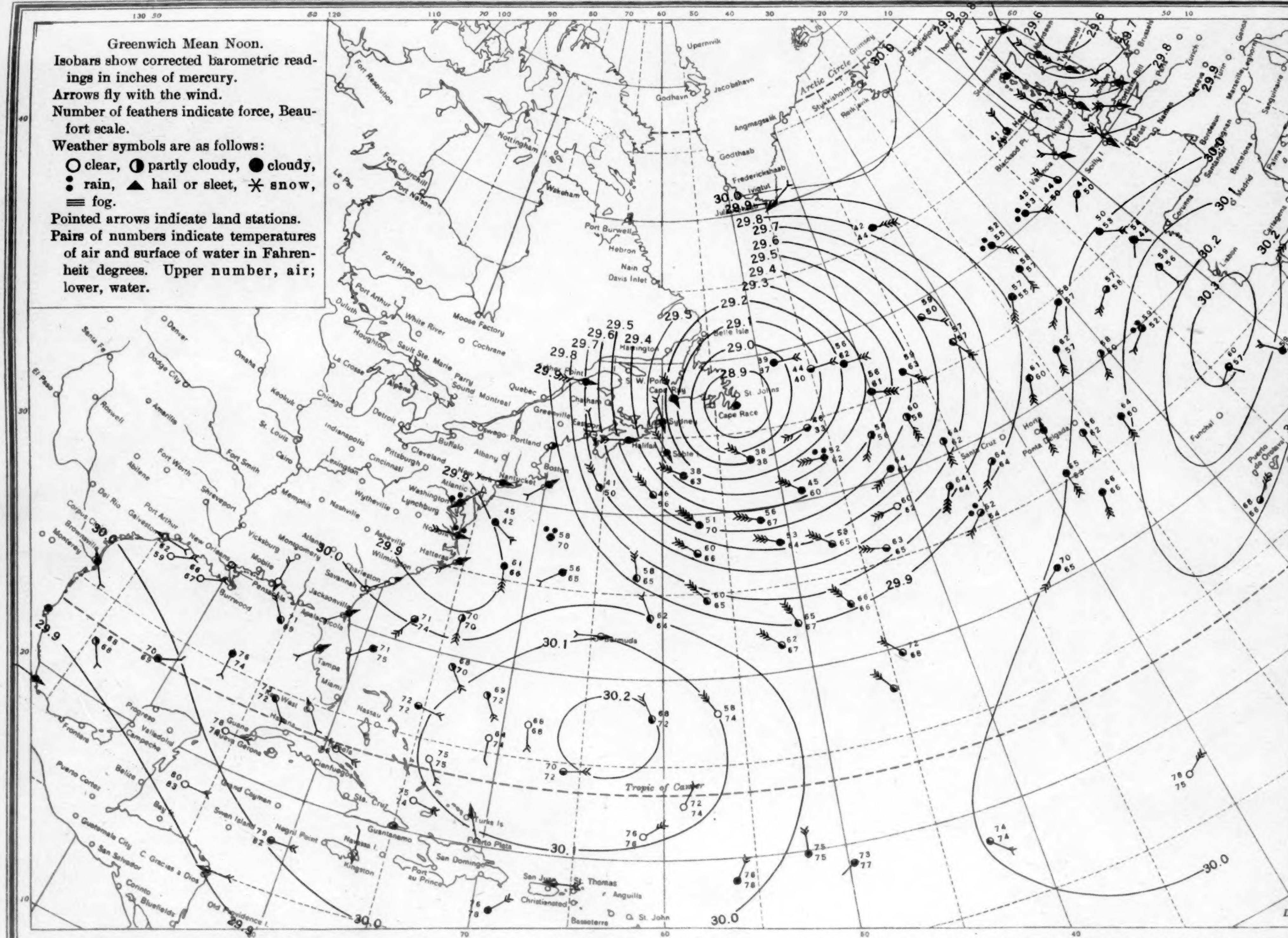


Chart VIII. Weather Map of North Atlantic Ocean, March 1, 1931

Chart VIII. Weather Map of North Atlantic Ocean, March 1, 1931

(Plotted by F. A. Young)



Greenwich Mean Noon.

Isobars show corrected barometric readings in inches of mercury.

Arrows fly with the wind.

Number of feathers indicate force, Beaufort scale.

Weather symbols are as follows:

○ clear, ◑ partly cloudy, ● cloudy, ⁚ rain, ▲ hail or sleet, ✳ snow, ≡ fog.

Pointed arrows indicate land stations.

Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

Chart IX. Weather Map of North Atlantic Ocean, March 2, 1931

(Plotted by F. A. Young)

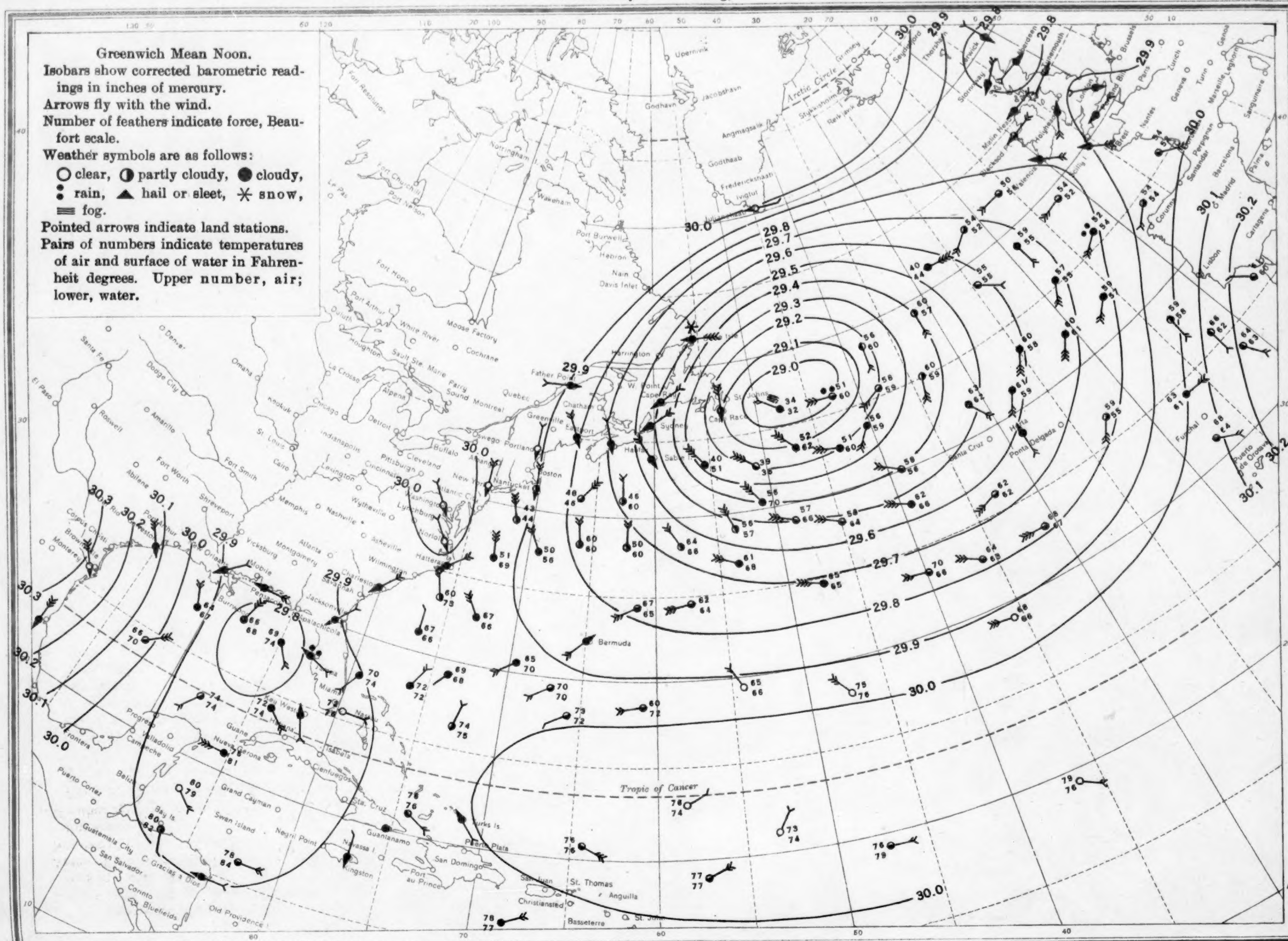


Chart X. Weather Map of North Atlantic Ocean, March 3, 1931

Chart X. Weather Map of North Atlantic Ocean, March 3, 1931

(Plotted by F. A. Young)

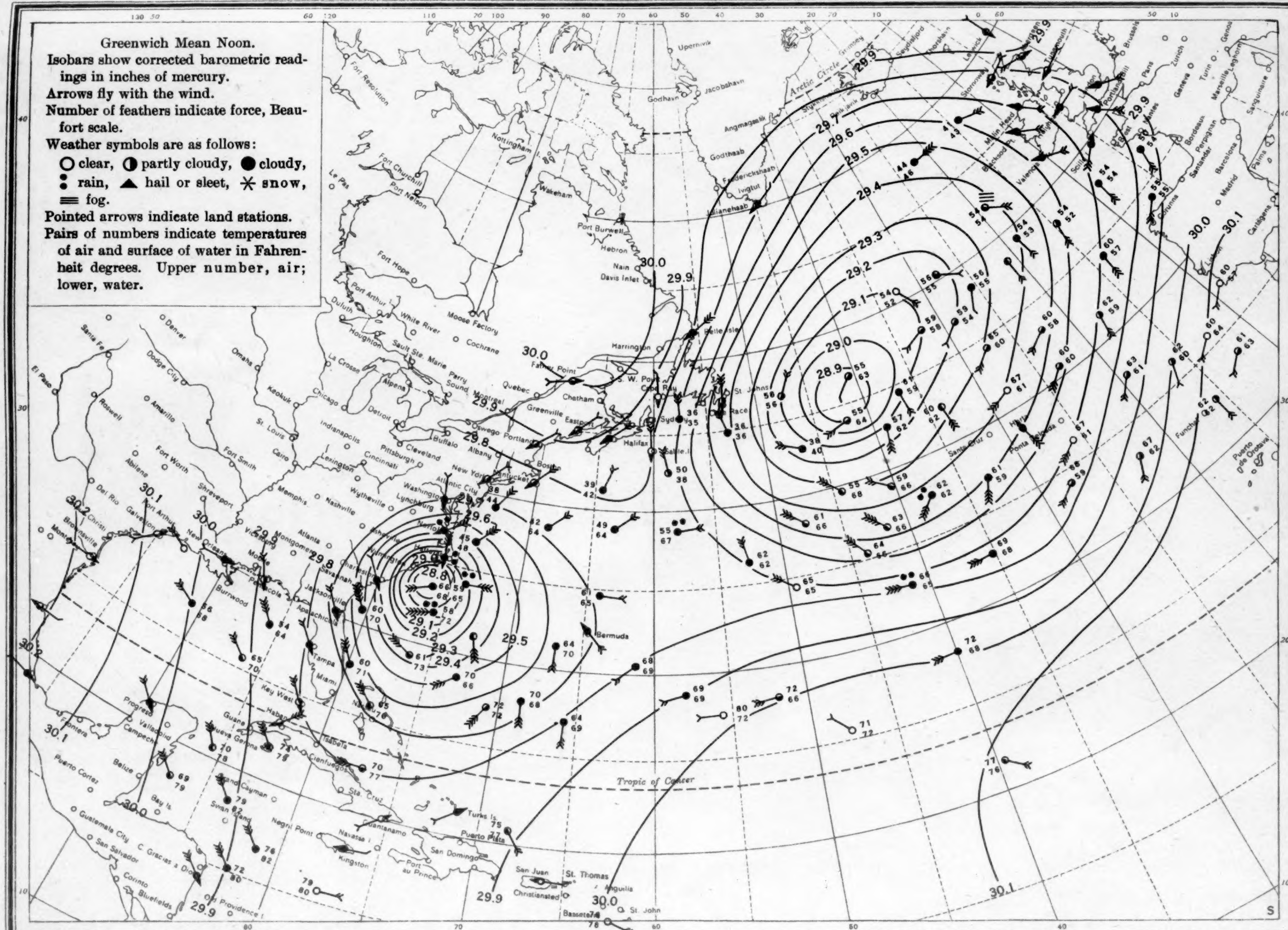


Chart XI. Weather Map of North Atlantic Ocean, March 4, 1931

(Plotted by F. A. Young)

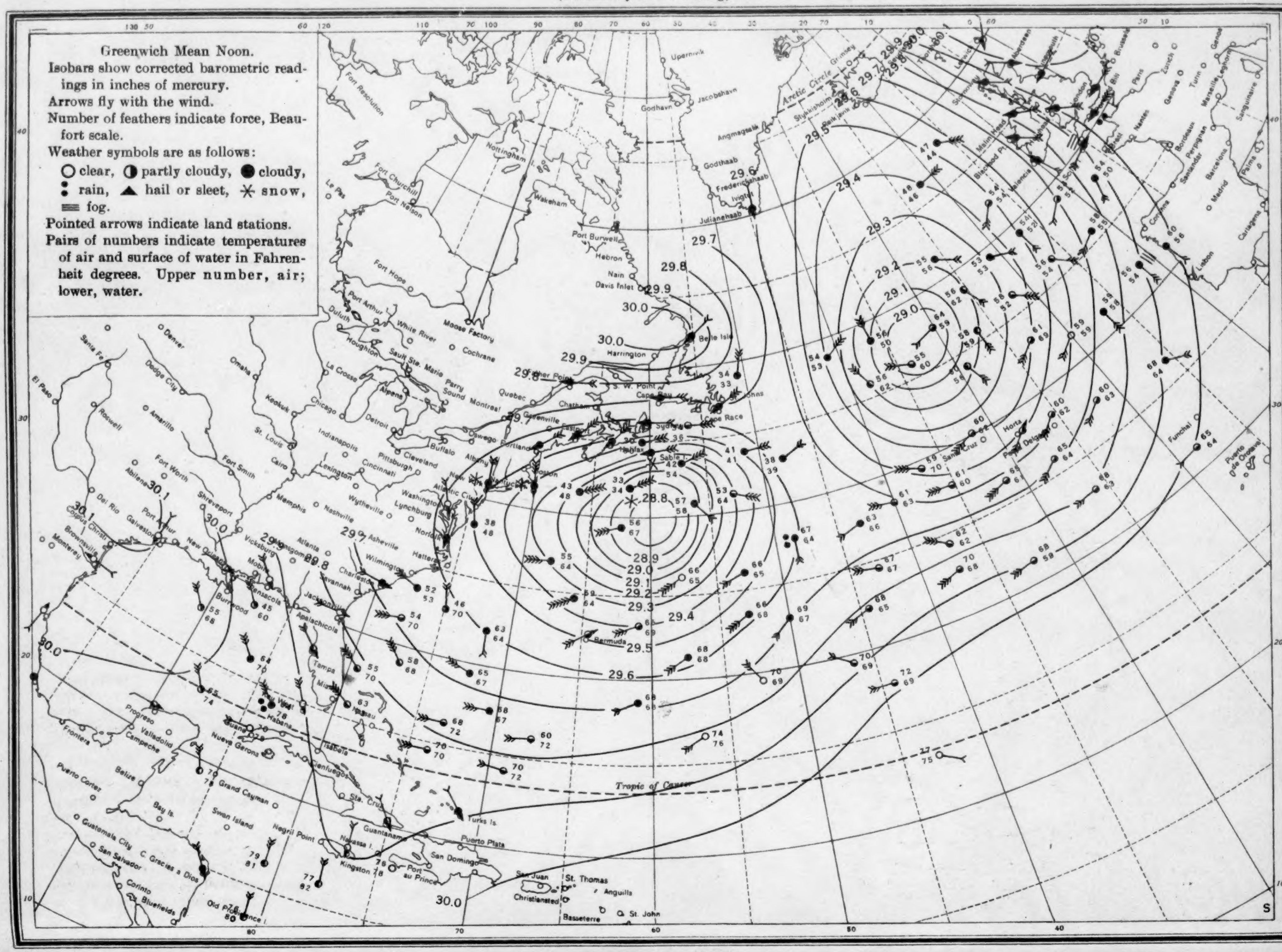


Chart XII. Weather Map of North Atlantic Ocean, March 5, 1931
(Plotted by F. A. Young)

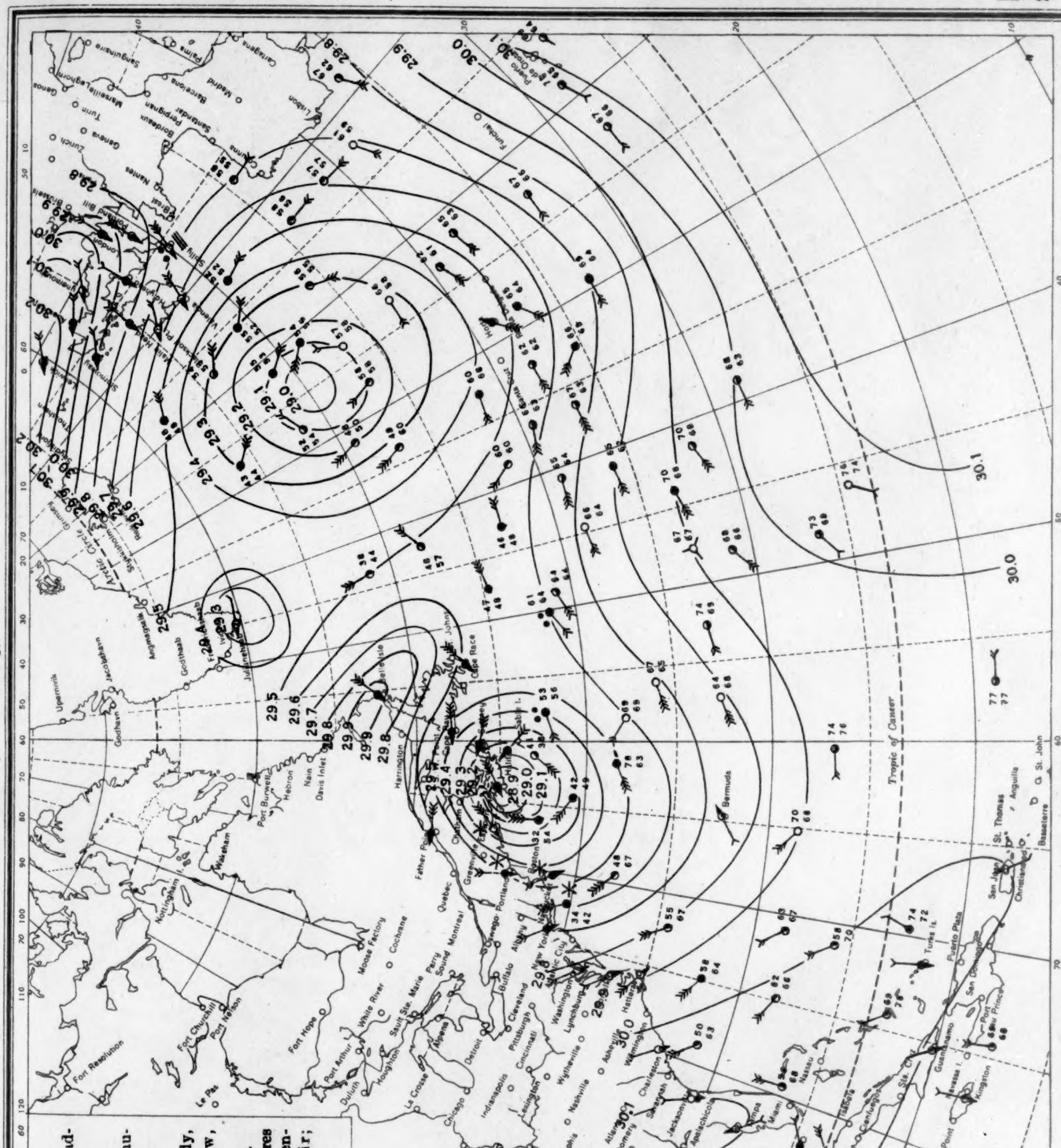


Chart XIII. Weather Map of North Atlantic Ocean, March 6, 1931

(Plotted by F. A. Young)